

Exploring the role of digital platforms in promoting value co-creation: evidence from the Italian municipal solid waste management system

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Abstract

Purpose – This study aims to explore how digital platforms (DPs) contribute to value co-creation in municipal solid waste (MSW) management systems.

Design/methodology/approach – The present paper conducts an explorative analysis using single case study methodology. The case in question involves a DPs operating in Italy.

Findings – Empirical analysis shows that DPs help engage citizens in MSW and reduce the fragmentation in waste management systems by fulfilling a brokerage role that connects citizens, municipalities and waste management companies. The development of bidirectional knowledge and resource flow among actors contributes to better waste recycling processes, as well as fosters economic, environmental and social value co-creation in a complex public service.

Research limitations/implications – This research is limited to a single case study within the Italian context, which may influence the generalizability of the findings. Future research could expand the scope to include multiple case studies across different geographical regions.

Practical implications – For practitioners and policymakers, this paper underscores the strategic benefits of adopting DPs in MSW management systems and thereby improving public service delivery.

Social implications – The case analysis highlights that DPs can assist public actors in achieving numerous sustainable development goals by enhancing recycling rates and activating learning mechanisms among citizens.

Originality/value – This study contributes to literature by connecting different fields of research (i.e. waste management and public management) and using network theory to show how DPs can contribute to the economic, environmental and social sustainability of MSW while generating relevant benefits for the actors involved.

Keywords Digital platform, Waste management, Municipal solid waste, Public service, Broker, Value co-creation

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1. Introduction

The global production of municipal solid waste (MSW) reached around 2 billion tons in 2020, with no signs of slowing down: Current forecasts expect that number to soar to 3.88 billion tons by 2050 (Maiurova *et al.*, 2022; World Bank, 2022). In Europe, specifically, MSW generation increased by 10% in recent years (Eurostat, 2024a). On average, a European Union (EU) citizen generates 249 kg of waste that is recycled, but 188 kg of MSW still ends up in landfills and 133 kg are incinerated. In addition, issues like urban littering, illegal dumps, the intensification of plastics in marine environments and the accumulation of microplastics in the food chain and human bodies still persist. All these aspects pose significant challenges, ranging from environmental problems to social health risks (Eurostat, 2023; Paletta *et al.*, 2019), leading to the enforcement of specific public policies (Al Mamun *et al.*, 2023; Expósito and Velasco, 2018) at the local, national and supra-national levels.

While searching for MSW alternatives, the EU has introduced a waste treatment hierarchy (Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, 2008) that prioritizes waste prevention (Zapata Campos *et al.*, 2020), followed by reuse and recycling, with disposal as a last resort. This Directive represents an important building block for the Circular Economy (CE) concept, later defined by the Waste Framework Directive revision in 2018 as a way to maintain the value of resources for as long as possible, even at the end of their lives. Since there are still major hurdles to the zero-waste ambition (Egüez, 2021; Foschi and Bonoli, 2019; Zacho and Mosgaard, 2016), recycling has become such a key circular practice that the EU Commission has set binding targets for all Member States: In particular, the EU Directive 2018/851 increased the MSW recycling rate from 50% in 2025 to 65% by 2035, as well as imposed a 10% maximum of waste to landfill for the same years. The same directive also incentivizes EU Member States to adopt more ambitious MSW measures than those set at the city level, which are generally limited to technological investment in collection and recycling facilities (Liu *et al.*, 2023). As part of the Agenda 2030, local governments are also urged to meet sustainable development goals (SDGs) (Abhayawansa *et al.*, 2021) that ask to reduce the adverse environmental impact (per capita) of cities by 2030 (SDG no. 11.6) and contribute to the National Recycling Rate (SDG no. 12.5.1.). With more secondary materials used in later production cycles, humans will draw fewer raw materials from the Earth (Ansani, 2012; De Souza Lima Cano *et al.*, 2022).

These institutional and normative pressures are prompting municipalities to consider integrated MSW to reduce landfilled waste and increase the quality of recycled materials. However, setting up local-level waste recycling strategies and plans that are coherent with macro-level waste management policies represents a challenge for municipalities (Moalem and Kerndrup, 2023; Zacho *et al.*, 2018). Beyond municipal budgetary constraints, the complexity of waste governance and citizens' poor engagement are the main hurdles to efficient and effective waste recycling strategies (Guerrero *et al.*, 2013; Hansen *et al.*, 2002; McDonald, 2017). Scholars maintain that municipalities and local governments should invest in communication and collaboration among business and non-business actors that affect waste recycling practices to increase all stakeholders' engagement and enhance MSW system governance.

Two streams of research provide arguments for this solution.

The public management literature (Alonso *et al.*, 2019; Cepiku *et al.*, 2022; Landi and Russo, 2022) and economic research on public service delivery (Di Liddo and Vinella, 2020; Fiorillo and Merkaj, 2024) both suggest that municipalities should set up new forms of collaboration that allow businesses and citizens to understand the benefits of sharing and integrating knowledge, information, skills and other resources (Yao and Miao, 2021).

When such integration takes place, the literature calls for a “value co-creation rationale” (Abhayawansa *et al.*, 2021; Bal *et al.*, 2023; Best *et al.*, 2018), which is considered a key step in generating sustainable services (Kruger *et al.*, 2018). Because the co-creation approach emphasizes a pluralistic model of public service based on collaborative partnerships, it is particularly suited for MSW governance, which is characterized by complex relationships between actors of the public, private and not for profit spheres (Agranoff and McGuire, 2003; Stoker, 2006).

Originally developed in the service management literature, the concept of value co-creation defines the “joint, collaborative, concurrent, peer-like process of producing new value” (Galvagno and Dalli, 2014: 644) through the active involvement of end-users at various stages of the process of creating and/or delivering a product or service (Pralhad and Ramaswamy, 2004; Vargo and Lusch, 2004). Hence, co-creation occurs whenever the resources of one system (i.e. the service provider) integrate with those available in other systems (i.e. the end-user) to facilitate the overall generation of value. Interaction may take place across the different phases of the production process: from users’ problem identification to product/service design, production *stricto sensu*, delivery and evaluation (Alves *et al.*, 2016; Messiha *et al.*, 2023). However, within the context of public services, co-creation is a relatively newer and more fluid concept (Brandsen and Honingh, 2016). It is often used interchangeably with co-production (Gebauer *et al.*, 2010), although the latter term has a longer tradition in the public management domain. Indeed, the landmark works of Ostrom (Alford, 2014) considered citizens’ co-production as intrinsic to the delivery of many public services (e.g. parental participation in childcare services, community engagement in clean and safe living environment). Co-production typically refers to citizens’ role as active co-implementors (and not just recipients) of public service delivery (albeit not in all phases) (Voorberg *et al.*, 2015).

In this particular context, co-creation means that the generated value cannot be appropriated by a single actor (e.g. a private firm) but should instead benefit various stakeholders. When a public entity (i.e. a municipality) contracts out a public service like MSW management, the service provider organization (also named PSO) is required to develop initiatives that are both economically feasible and socially legitimate (Dijkgraaf *et al.*, 2003; Park and Moon, 2023). The final expected outcome should create public value for both individual end-users and society in general (Osborne *et al.*, 2016; Torfing *et al.*, 2021). This is the case of “social innovations,” such as the introduction of collective waste disposal schemes (Ben-Ari, 1990) and deposit refund schemes that are based on citizens’ active participation.

The second stream of research is the waste management literature, which takes a more technical approach and uses a different language (De Souza Lima Cano *et al.*, 2022) to establish that effective collaboration in MSW management has two fundamental prerequisites: (i) citizens’ engagement in properly sorting waste at the source and (ii) a well-established waste collection infrastructure, usually made available by local governments in partnership with business actors.

With reference to the first prerequisite, Hoornweg and Bhada-Tata (2012) demonstrated that the quality of separation at the source can significantly influence the quality of recycled materials. Separation at the source usually happens at citizens’ houses with allocated waste bins depending on local MSW policy. It requires citizens’ technical knowledge of waste composition, willingness to properly separate waste by material, as well as the acceptance and support of the public (Ally *et al.*, 2016; Sozoniuk *et al.*, 2022). Yet, the nature of waste is not always clear for citizens: Product characteristics and packaging design are constantly evolving, leading to complexity in waste sorting and recycling (Deutz *et al.*, 2010).

In addition, waste collection routes and treatment techniques vary from city to city, with huge divergences between urban and rural areas, creating confusion among citizens and temporary users like tourists (Soltani *et al.*, 2015). To compound this issue, citizens' engagement in effective waste recycling is often very limited from the onset (Joseph, 2006) because they perceive MSW management as being the sole responsibility of the public administration (Kala *et al.*, 2020). Kala *et al.* (2020) noted that citizens' lack of commitment reasonably stems from their lack of involvement in the decision-making phase: Most decisions on MSW management are made by a small, select group of public-private entities and technical experts. It follows that residents' empowerment is crucial in effective waste recycling (Gundupalli *et al.*, 2017; Ganesan, 2017; Joseph, 2006; Mmereki *et al.*, 2016).

With reference to the second prerequisite, it is widely acknowledged that recycling involves various actors of the so-called recycling value chain: from households and waste collectors to logistics companies, sorting plants and waste recycling facilities (Du Rietz, 2023). While some countries have highly centralized MSW management systems entrusted to a large and vertically integrated organization that handles waste collection and processing, many other countries opt for a more decentralized approach (Fernández-Nava *et al.*, 2014; Levaggi *et al.*, 2018) which relies on the interconnectedness and interoperability of various processes and actors (Iacovidou *et al.*, 2017; Wilson and Velis, 2015). The decentralized approach is based on the underlying assumption that externalization of public services can lead to greater efficiency and quality of public service delivery while reducing costs (Alfiero *et al.*, 2017; Citroni *et al.*, 2016; Kuhlmann, 2010). Nevertheless, MSW management systems often lag behind in efficiency, due to a lack of collaborative synergies among the diverse actors in the recycling value chain. The governance of MSW requires a cohesive network of business and nonbusiness actors to achieve efficient waste management and promote closed loop schemes (Song *et al.*, 2015). Therefore, it is useful to conceptualize MSW governance as a network of processes (i.e. activities) and structures (i.e. connected actors), defined by the interactions and relationships among local authorities, waste collectors, households, processors and regulatory bodies that play key roles in different stages of waste management (Du Rietz, 2023; De Souza Lima Cano *et al.*, 2022).

One mode for improving network efficiency is the adoption of digital platforms (DPs). Such platforms are already used in various public services to integrate online and offline activities into a unified program (Meijer and Boon, 2021; Petrescu, 2019; Torfing *et al.*, 2021; Yu *et al.*, 2019) to facilitate value co-creation (Mu *et al.*, 2022). This paper assumes that DPs can likewise contribute to citizens' engagement and collaboration among actors in the MSW management. However, the use of DPs in MSW has received relatively little attention in the waste management literature (Kurniawan *et al.*, 2022; Olivetti and Cullen, 2018; Sarc *et al.*, 2019). Much more attention has been given to other key enabling technologies, such as sensor-equipped smart bins, robotic automation and GPS-driven semi-autonomous trucks (Guyot Phung, 2019) that enhance technical performance (Khadke *et al.*, 2021; Wang *et al.*, 2021) and monitor waste collection, transportation and recycling operations (Borchard *et al.*, 2022; Cheah *et al.*, 2022; Kannan *et al.*, 2024; Khadke *et al.*, 2021; Sarc *et al.*, 2019). In addition, the public management literature lacks investigations into how DPs can support citizens' engagement and business actor collaboration within MSW management systems. Therefore, this work aims to address this gap by exploring the functioning of DPs in this specific sector, which requires collaboration among a diverse array of actors, including public and private entities, businesses and citizens.

In detail, this paper tries to address the following research question RQ: How do DPs enable knowledge-sharing and collaboration mechanisms among the different actors of the MSW management system and thereby produce a value co-creation process?

To address this research question, this study conducted an exploratory analysis based on a single case study (Eisenhardt, 1989; Yin, 2003) focusing on Alpha, an innovative small-sized firm located in Italy that has developed a DP designed to (i) assist households in accurately sorting their waste, and (ii) facilitate connections between municipalities, waste management companies and citizens. Since 2015, this Italian firm has made its DP accessible to 1,600 Italian small, medium and large municipalities. This case choice is especially relevant because Italy boasts one of the highest MSW recycling rates in Europe (Eurostat, 2024b), despite the considerable fragmentation of its MSW management systems and waste sorting rules (Sarra *et al.*, 2019). The empirical analysis herein draws from network theory, and specifically, Ciulli *et al.*'s (2020) application of it to explore the role of DPs in food recovery supply chains informed by CE goals. Similarly, this paper investigates how DPs contribute to value co-creation processes in the domain of MSW management.

The findings show that the introduction of DPs in MSW management systems (1) activate bidirectional knowledge and resource flows mediated by artificial intelligence (AI) integration; (2) mitigate system fragmentation by serving as an effective “broker” that connects parties and facilitates collaboration; and (3) enhance waste recycling performance. Ultimately, the DP generates multiple benefits for waste management, including lower water and energy usage, reduced operational costs, greater citizen awareness and stewardship and less environmental pollution. Based on this evidence, the case analysis contributes to the literature on the role of DPs in stimulating public value creation (Meijer and Boon, 2021; Torfing *et al.*, 2021) by using network theory as interpretative lens (Ciulli *et al.*, 2020).

The case analysis also shows that in decentralized systems, key actors embedded in the recycling value chain exhibit a lack of interconnectedness that the public management literature has often taken for granted. This limitation is addressed in the present paper by integrating the network approach, adopted in waste management literature focusing on supply chain optimization (Cohen and Gil, 2021; Eghbali *et al.*, 2022), with public management research on public service delivery (Osborne, 2010). By doing so, this paper offers two novel insights: (i) it might be beneficial for public management researchers to shift the focus beyond PSOs as primary creators of value, recognizing that value emerges from interactions between citizens and other public/private actors, and (ii) the nascent literature on public service ecosystems (Trischler and Charles, 2019) could benefit from exploring the mechanisms that favor the emergence of interactive service ecosystems up to societal beliefs and value for a greener planet (Osborne *et al.*, 2022). In this regard, DPs represent a promising mode to connect seemingly sparse actors that were not fully explored in prior research and that has the potential to animate public service ecosystem debate.

The remainder of this paper unfolds across five sections: Section 2 reviews the existing literature on MSW management and the value co-creation process, as well as describes the analytical framework used to interpret the case study. Section 3 outlines the methodology. Sections 4 and 5, respectively, present and discuss the findings. Finally, Section 6 concludes with the implications and limitations of this research.

2. Literature review

2.1 *Toward value co-creation in municipal solid waste management systems*

There are relatively few studies that focus on using network-oriented and information-sharing mechanisms to address collaboration and interaction in MSW management systems, and thereby enhance citizens' engagement and optimize waste governance (Cohen and Gil, 2021; De Souza Lima Cano *et al.*, 2022; Eghbali *et al.*, 2022; Kurniawan *et al.*, 2022). In their literature review, De Souza Lima Cano *et al.* (2022) analyzed the formal and informal networks of stakeholders in different recycling value chains, observing how local contexts

strongly influence the capacity and structure of actor networks involved. The authors identified two key categories of stakeholders – such as intermediate traders and informal waste pickers, which are common in low-income countries – and emphasized the need for more interconnections and information-sharing throughout the whole value chain. However, their review also treated households solely as waste generators and did not consider DPs as a possible solution for greater interconnectedness among actors. [Cohen and Gil \(2021\)](#) partially filled the latter gap by discussing the potential of digital technologies to enhance waste management. Their research examined the barriers to knowledge sharing among recycling value chain actors, mainly related to diverse waste vocabularies, scarce compatibility of data formats and poor interoperability between the MSW system elements. The authors proposed that municipalities adopt a relational database that formalizes the components or actors of the MSW system and their relationships and thereby overcome siloed mechanisms. Their work is useful for formulating a database architecture, but it does not consider actors' dynamics in using shared data. Their analysis focused on the technical level, without deepening how knowledge-sharing favors the retention of materials and the valorization of resources. [Eghbali et al. \(2022\)](#) offer a more useful investigation on how programs aimed at bolstering citizens' knowledge and awareness about recycling enhance their collaboration. Starting from the premise that "most people are unwilling to use separate bins to separate waste at home" ([Eghbali et al., 2022: 2](#)), the authors posit that appropriate and accessible infrastructure for recycling can significantly contribute to better MSW management, if paired with information programs about recycling and incentive mechanisms that motivate citizens to sort waste. In short, citizens' knowledge and motivation are key levers in solidifying their role as co-implementers of MSW systems. That said, their study did not address digital solutions. [Kurniawan et al. \(2022\)](#) discuss the delivery of reward mechanisms through online transactions by examining the introduction of a DP in Indonesia. Their findings indicate that the DP fostered the growth of the informal waste pickers sector, which matches supply with demand, encourages local communities to co-implement the MSW collection service and connects citizens' engagement with the waste recycling industry's needs.

In sum, several studies do not explore the role of DPs in relation to collaboration and citizens' engagement, and others lack insight into the dynamics of collaboration. However, it is imperative to consider the information dynamics between actors in the recycling value chain, especially since many of the works assume that said actors can be easily connected ([Vasconcelos et al., 2022](#)). Finally, the cited studies have only discussed the benefits or impacts of collaboration in relation to creating economic value through the market of secondary materials processed from the recycling facilities ([Govindan et al., 2015](#); [Guide and Wassenhove, 2006](#); [Guide and Van Wassenhove, 2009](#)).

A more promising perspective is to examine how knowledge sharing and collaboration among recycling value chain actors may also contribute to environmental and social benefits, aligning MSW management plans with broader sustainability goals ([Chaabane et al., 2012](#); [Rao and Holt, 2005](#); [Seuring and Müller, 2008](#); [Urbinati et al., 2017](#)). It follows that the public service organizations (PSOs) that usually manage MSW have the potential to spur new configurations in waste management systems, going beyond PSOs' boundaries and engaging various actors to enable shared environmental and social value and so, higher societal value ([Iacovidou et al., 2017](#); [Urbinati et al., 2017](#)). Such efforts could limit the negative environmental externalities associated with MSW treatment while improving community engagement around waste management and prevention ([Mattera et al., 2020](#); [Sondh et al., 2024](#)).

Pragmatically, PSOs may adopt a co-creation approach that connects the community of direct recipients of the MSW services (i.e. citizens and other users) and MSW service providers in the design, management and delivery of services. This approach emphasizes users' dual role as beneficiaries and activists, which necessitates a cooperative, network-based service production system (Alfiero *et al.*, 2017; Laitinen *et al.*, 2018; Landi and Russo, 2022; Maiurova *et al.*, 2022; Osborne *et al.*, 2016; Osborne *et al.*, 2021; Pestoff, 2006; Petrescu, 2019; Voorberg *et al.*, 2015). As highlighted by Landi and Russo (2022), who investigated MSW collection services, PSOs with a positive attitude toward co-creation exhibit higher levels of recycling performance – suggesting that the active involvement of citizens and other service users improves waste collection and segregation. In this vein, co-creation processes also have the ability to restore legitimacy to citizens' involvement, a fact that the MSW management literature has largely neglected.

2.2 *Optimizing information-sharing and stakeholder engagement in municipal solid waste systems by using digital platforms to fill circularity holes*

Granted, there are considerable challenges to implementing co-creation processes among diverse actor groups with varying needs as in a recycling value chain (Svingstedt and Corvellec, 2018). One of the most important stems from missing relations among actors, which do not allow actors to get access to pertinent information and knowledge held by other(s). Network theory defines this lack of direct ties among actors as “structural holes” (Burt, 1995, 2008). Ciulli *et al.* (2020) recently refined this concept in the context of food recovery, describing situations where actors in a network are not well connected and food becomes discarded waste, because of difficulties arise in integrating knowledge and fostering collaboration. The novel concept introduced by Ciulli *et al.* (2020) is defined as “circularity holes” and has two distinctive characteristics: (a) a circularity hole leads to a loss of residual value in waste because waste does not flow to other recycling chain actors: it is discarded by its owner before reaching possible alternative uses/treatments or waste is mismanaged once the end-of-life condition is exceeded (Wijewickrama *et al.*, 2021). Thus, circularity holes reduce the flow/circularity of materials in MSW, leading to a loss of value and generating negative environmental and social externalities; (b) a circularity hole exists because the value of waste is not recognized by its owner and/or the potential receiver who lacks in knowledge of how waste can be transformed into valuable resources and are not aware of the negative impacts associated to waste mismanagement.

Both Burt (1995, 2008) and Ciulli *et al.* (2020) argue that these holes can be patched by using brokers, who help to retain resource value for as long as possible by promoting upcycling (rather than downcycling) practices (Wilson, 2016). Specifically, these brokers fulfill six different roles: connecting, mobilizing, informing, protecting, integrating and measuring.

Connecting is the broker's most central role (Ciulli *et al.*, 2020). Brokers facilitate the creation of connections between different types of actors in the recycling chain, effectively building bridges between previously disconnected parties on opposite sides of the structural and circularity holes (Marsden, 1982; Obstfeld, 2005). This process involves identifying potential actors, such as waste producers and those who can valorize waste, and enabling their interaction to facilitate the flow of information and resources (Kirkels and Duysters, 2010; Pollock *et al.*, 2004; Stovel and Shaw, 2012). Connecting is a pre-requisite for mobilizing the actors involved, such as public institutions and waste management companies and, therefore, fostering the involvement of potential stakeholders (i.e. citizens) (Kirkels and Duysters, 2010; Obstfeld, 2005). The informing role entails providing critical information to the connected actors. This includes sharing the necessary knowledge to engage in waste

recovery, which facilitates smoother transactions and more effective collaboration between brokered parties (Marsden, 1982; Obstfeld, 2005). Brokers may also serve a protective function when they ensure that the transactions between actors are safe, secure and compliant with relevant regulations. Finally, brokers' integrating role means linking the waste recovery processes with existing systems and technologies used by the actors in the recycling chain. This involves incorporating technology into the existing MSW operations as well as providing tools for tracking and measuring the impact of waste recovery efforts (i.e. measuring).

In line with this viewpoint, this study applies the concept of circularity holes to the MSW management domain. It is clear from practice and scholarship that waste recycling operations are a "wicked problem" (Elia and Margherita, 2018) that require a full integration of different knowledge and information owned by various (often disconnected) actors. Thus, this paper searches for intermediate entities or technologies that may act as "circularity brokers" who can connect both business and nonbusiness actors to facilitate value co-creation processes.

The brokerage function can be performed by intermediary organizations operating in the MSW system that can, in turn, leverage modern technologies like blockchain (De Villiers *et al.*, 2021) and other key enabling technologies of Industry 4.0 (Kurniawan *et al.*, 2023). Also, DPs may support better system functioning. Specifically, DPs can help to better monitor waste collection and treatment operations, as well as facilitate information exchange (Guyot Phung, 2019) between citizens, municipalities and waste management companies (França *et al.*, 2020). In other words, circular brokers, with the support of DPs or DPs themselves, may accelerate value co-creation processes and thereby improve the economic, environmental and social benefits deriving from waste recycling in MSW systems.

3. Methodology

Given the explorative nature of its RQ, this paper follows a qualitative approach based on an in-depth single case study (Eisenhardt, 1989; Yin, 1994). The case study methodology is well suited for novel research problems (Halinen and Tömroos, 2005), such as the poor use of co-creation in the domain of MSW management (Kruger *et al.*, 2018). Notably, this case study follows an inductive route for coding information and elaborating results, which suits the purpose of identifying both the interaction patterns and knowledge exchange that underlie the value co-creation process within MSW management systems.

3.1 Case selection

The chosen research context for this study is the EU, selected for its complex and distinctive waste management landscape. While the existing literature on waste management and digitalization is predominantly concentrated on developing countries, especially in the Asia Pacific region (Kurniawan *et al.*, 2022; Kurniawan *et al.*, 2023), Europe presents an idiosyncratic challenge. The EU's specific approach to waste management – uniquely blending regulatory, environmental and technological dynamics – offers a rich setting for exploring waste management strategies in a developed region:

- The EU has a waste-centric and product-specific regulation framework, with a plurality of binding and nonbinding measures and actions that focus on the promotion of a "waste hierarchy" management (Miliotis, 2018). Driven by the desire to lead on waste management policies, the EU Commission introduced ambitious waste recycling and prevention measures (Castillo-Giménez *et al.*, 2019; Morsetto, 2020). As part of the Waste Framework Directive revision, the Commission set the target of 65% of municipal waste recycled by 2030 and a reduction of municipal waste landfilled to a maximum of 10%.

- European nations are distinguished by companies and municipalities that are deeply committed to sustainability and the CE. The coming years will see extensive investments in waste management infrastructure, with a focus on digital infrastructure, social services and climate change mitigation ([European Investment Bank. and Ipsos Public Affairs, 2021](#)).
- The structural conditions in Europe are conducive to adopting advanced Industry 4.0 technologies ([Castellano and Bogarelli, 2023](#)) in MSW. Countries like Germany, Norway, Sweden and Switzerland are pioneers in this area, particularly in the application of robotics in waste management, which is expected to expand beyond sorting to collection and street sweeping (EIONET Report, 2020).

The case selection process was articulated in two steps: (1) identifying a suitable geographical local context based on the DPs operating in MSW management systems and (2) analyzing the competitive landscape of DPs.

Step 1: Identifying a suitable EU local context served by DPs in MSW management systems.

In the first step, this study examined the EU landscape of DPs for waste management that address citizens' information needs about sorting and other MSW services. The goal was to understand how innovative digital solutions for waste recycling address citizens' and other actors' collaboration. The initial observations revealed that DPs differ according to the waste governance and infrastructure that dominate each country.

The EU member states that use highly centralized MSW management systems are characterized by the presence of various platforms developed by telecommunications companies serving as generalist smart city applications – such as the “My City in My Pocket” DP by Orange in France, and “My city DP” by Telekom in Germany. In addition, there are DPs developed by software houses that provide cleantech solutions for retail chains. These DPs are designed to enhance waste recycling for specific branded products (i.e. Carrefour) by offering material rewards to end-users.

In countries with more decentralized MSW management systems, regional authorities or municipalities predominantly handle or outsource waste management services, resulting in a variety of processes, structures and actors across the national territory ([Alfiero et al., 2017](#)). The resulting regional disparities in waste collection services have led to the diffusion of many apps and digital tools whose scope is limited to local areas. In addition, such disparities impact efficiency ([Sarra et al., 2019](#)), thus, creating a need for new digital tools that can simplify waste management operations by linking recycling value chains, local governing bodies and households.

The Italian context offers a useful case study in this regard because of the great fragmentation in its waste governance and the lack of harmonization among waste collection and management practices across the country ([Sarra et al., 2019](#)). In addition, Italy is ranked third in terms of municipal waste generated by EU-27 countries ([Eurostat, 2024b](#)), with its 30,023 millions of metric tons, while being able to recycle 49.2% of its waste in 2021 ([ISPRA, 2023](#)). Furthermore, the recycling industry has become a significant and strategic sector in the national economy: It encompasses more than 4,800 companies with 236,000 employees, saw its value increase by 31% between 2010 and 2020 ([Circular Economy Network, 2022](#)), and is currently worth 10.5 billion euros. In this context, Italian firms are widely adopting ICTs to improve waste recycling performance ([Casazza et al., 2019](#)). Among them, digital waste tracking systems are used to monitor hazardous and nonhazardous waste traceability; cloud computing systems are adopted to store waste management infrastructure information; smart bins are introduced to record the mixed waste

generated from residential activities, while apps and other DPs are implemented to increase citizens' awareness about proper MSW management practices.

Step 2: Analysis of the DPs' competitive landscape.

Based on the authors' analysis, the Italian competitive landscape in 2023 was characterized by the presence of 14 main DPs operating in MSW management systems, accounting for 2,436 million downloads from the Google Play Store. Some of them support local or regional MSW services, while others compete at the national level. All 14 DPs were downloaded and used to properly categorize them. Twenty-four features were identified that aligned with four major categories (see [Table 1](#)): (i) Type A specialized, (ii) Type B generalists, (iii) Type C owned by waste managers, (iv) Type D owned by communication agencies.

In terms of availability, Type A accounted for 14.3% of the total, Type B for 14.3%, Type C for 50% and Type D for 21.4%. Thus, DPs owned by waste management companies represented the majority of the total DPs available in Italy. However, the most downloaded and highest-rated DPs were the specialized ones (Type A), with 2 million downloads from Google's Play Store. Citizens and other end-users (e.g. travelers) preferred Type A apps, which seem to have greater potential to engage them in contributing to better sorting at the source. On this point, it is interesting to note that although waste management companies' DPs represent the second-most downloaded, they also feature the worst ratings – despite offering more features such as “Geolocation” and “Calendars” ([Figure 1](#)).

This paper identified a Type A DP to understand how digital technologies engage citizens and favor relationships among various actors in the recycling value chain. The selected DP is a Software as a Service (SaaS) of Alpha, which is an innovative (according to Italian law) small-sized Italian enterprise, with its core operations centered around software development tailored for waste management services.

3.2 Data collection

Data collection took place between November 2022 and December 2023 and was primarily based on direct semistructured interviews. The semistructured approach allowed to guide the discussion, while a small set of standard questions helped to maintain a basic level of scope and consistency.

Data were collected in multiple waves, following an iterative respondent-driven sampling approach ([Heckathorn, 1997](#); [Lu, 2013](#); [Neumeyer and Santos, 2018](#)). The process started with an initial seed of two participants ([Neumeyer and Santos, 2018](#)) who represent Alpha's founders. These initial two interviews elicited the names of other relevant actors in their network (e.g. name generators questions) ([Marsden, 2003](#)). Those actors represent stakeholders in the MSW system with whom Alpha shares specific relationships. Notably, the actors were embedded in pre-defined conceptual categories ([Wejnert, 2010](#)) (i.e. municipalities, waste management companies, regional authorities and national authorities).

The next step involved selecting the actors to be interviewed based on referrals provided by Alpha about specific or peculiar cases ([Neumeyer and Santos, 2018](#)) while also considering their diverse characteristics (in terms of size and geographical location). This process enabled a full mapping of the ego network of the case study, ensuring theoretical saturation. The selection process continued until all constructs under consideration (i.e. issues, themes, categories and linkages) were adequately addressed.

Furthermore, secondary data were obtained from corporate and institutional websites, companies' financial and sustainability reports were downloaded from the Orbis database and data on recycling rates were retrieved from the Italian Institute for Environmental Protection and Research (ISPRA) repository. The secondary data were used to (a) provide

Table 1. Overview of DPs features for MSW management

Features	Description
1. Business feature	<ul style="list-style-type: none">• Nature of the platform owner: This feature describes who owns the DP because ownership type can influence the DP's objectives, operations, and services offered
2. Technical features	<ul style="list-style-type: none">• Accessory functions: Additional functionalities that support the core purpose of the DP (e.g., settings customization, or integration with other apps)• AGID certifications: AGID, the Italian Digital Agency, issues certifications. This feature specifies whether the DP's service provider is certified, ensuring compliance with national standards for security and data protection• Advertising: This feature details if the DP incorporates third-party advertising• Multi-languages: This feature indicates the DP's capability to support multiple languages
3. Sales/marketing features	<ul style="list-style-type: none">• Free: This feature indicates that the DP is free to download and use• Subscription-based: This feature describes the existence of a premium model for waste management companies and/or municipalities. A fee grants the upload of context-specific content
4. Geolocalization features	<ul style="list-style-type: none">• Geolocated users: The DP provides location-based services as being able to determine a user's position• Geolocated calendars: Includes waste collection calendars customized to the user's location• Geolocated Maps: Display various waste-related points of interest, like recycling centers, based on geographical location
5. Informative features	<p>Downstream information to users</p> <ul style="list-style-type: none">• Waste categories: Details on various waste types and disposal or recycling methods• Bulky waste collection: Provides information about collection services for large or bulky items• Calendars: Shows schedules for regular waste collection, special pick-ups, and recycling events• Green news: Delivers news and updates on environmental topics, recycling tips, and sustainability trends• Info update: Regularly updates waste management information, policies, and guidelines• Listing of collection points: Enables users to get access to waste collection point locations• Notifications: Alerts and reminders about collection dates, policy changes, and important events• Street sweeping: Information and notifications about street sweeping schedules

(continued)

Table 1. Continued

Features	Description
	Upstream information from users: <ul style="list-style-type: none"> • Direct calls: Facilitates direct calling of relevant waste management services • Feedback: A system to get users' feedback on recycling habits or address inquiries • Reporting degradation: Users can report areas of waste or environmental degradation • Reporting missing waste: A feature for reporting uncollected waste as scheduled • Notice board for re-use of objects: citizens can publish advertisements for their goods that they no longer use making them available to other fellow citizens through re-use centers organized by municipalities
6. AI features	<ul style="list-style-type: none"> • Product recognition: An AI-driven tool identifying products and suggesting recycling methods via image recognition • Recognition of Mobius Loop symbols: AI functionality to identify Mobius Loop symbols on products and packaging, informing users about the materials for recycling

context for this research, (b) understand the peculiarities of DP providers and waste management companies and (c) assess various operational and strategic facets, such as the nature of the business, geolocation, the populations served and their DP adoption rate.

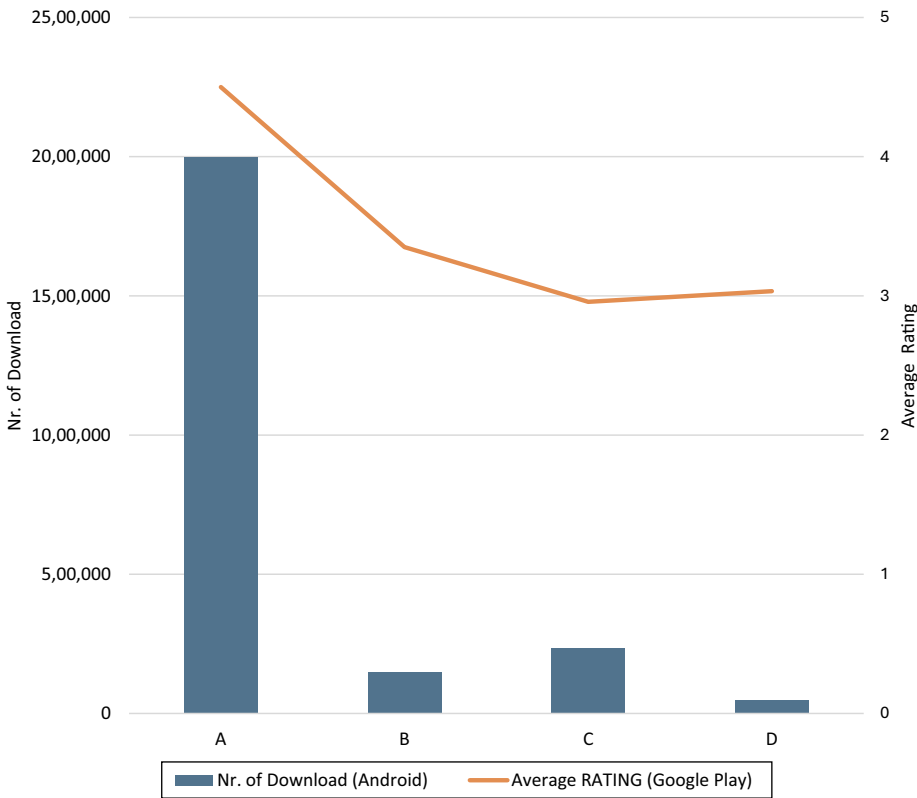
The first part of the research concentrated on exploring the creation, diffusion and features of the DP through interviews with two founding members and the “social media and communication officer” of Alpha. These individuals, who held a mix of managerial and technical roles, provided an understanding of the ways in which the DP shares and integrates knowledge, fosters relationships among value chain actors and ultimately creates value (Hauke-Lopes *et al.*, 2023).

The second aspect of the study was dedicated to understanding the viewpoints of various actors. To achieve this, the research team engaged with the managers of waste management firms and civil servants of municipalities that used the DP, as well as with national regulatory agencies that oversee the waste management sector. The aim was to understand how these entities incorporate the DP into their existing operations and what benefits they observed. The discussions revolved around several critical topics, such as the potential of DP in reaching and engaging citizens, connecting recycling chain actors and contributing to sharing knowledge and generating multiple tangible and intangible values.

A total of 13 interviews were conducted, either face-to-face or via Microsoft Teams (De Villiers *et al.*, 2022). All the interviews were recorded and transcribed *verbatim*. The interviews were 1 h long on average (see Table 2).

3.3 Data analysis

The interviews were analyzed inductively by means of open coding, following Gioia *et al.*'s (2013) guidelines for an open coding process (Ciulli *et al.*, 2020; Trevisan *et al.*, 2023).



Note: A, B, C and D identifies the four different types of DPs

Source: Authors' own work

Figure 1. Comparative analysis of downloads and average user ratings for waste management DPs on Android

The inductive content analysis method (Elo and Kyngäs, 2008) was used to uncover patterns with less risk of confirmation biases resulting from pre-established codes or templates. The RDQA package supported the content analysis (Salvini, 2014). As recommended by Miles *et al.* (2014), the coding process followed two analysis cycles: In the first cycle, codes were generated through descriptive open coding that synthesized an idea in a sentence or paragraph. In the second cycle, the initially generated codes were categorized into theoretical dimensions representing the emerging patterns (see Table 3).

4. Case study description and findings

Following the stated methodology, subsection 4.1 presents the interviews with Alpha's management team that depict the DP's creation process and its features. Subsection 4.2 presents the perspectives of ego-network institutional actors regarding the citizens' participation. Finally, subsection 4.3 describes the types of values that the DP created according to all interviewees.

Table 2. Interviews' information

Actors	Interviewees	No. of interviews	Duration	Period
Alpha	Head of marketing and communication (co-founder M)	2	1 h; 30 min	November 2022; July 2023
Alpha	Technical director (co-founder D)	1	1 h	November 2022
Alpha	Social media and communication officer	1	30 min	July 2022
Waste management company A	Head of communication	1	1 h and 30 min	August 2023
Waste management company B	Head of services and urban sanitation	1	1 h	September 2023
Waste management company C	Operations manager	1	1 h	September 2023
Waste management company D	Head of corporate sales	1	1 h	October 2023
Municipality Theta	Counselor for urban planning and waste management	1	1 h	November 2023
Municipality Beta	Counselor for urban planning and waste management	1	1 h	November 2023
Municipality Epsilon	Counselor for urban planning and waste management	1	1 h and 15 min	December 2023
Region X	Officer for sustainable innovation and enterprises	1	1 h	November 2023
National authority for energy and environment	Member of board of director	1	50 min	October 2023

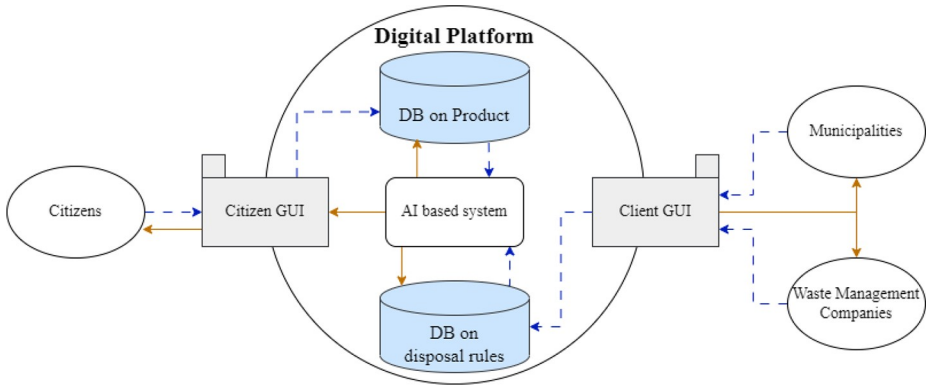
Source: Authors' own work

4.1 The development of a multisided digital platform for municipal waste management services designed to favor informative mechanisms and collaborative dynamics

Alpha, an innovative start-up founded in 2014, developed a DP to streamline waste segregation across Italy's diverse regions. The concept for the DP arose from the founders' frustration with the complexities of correctly sorting waste during their business travels due to the high geographic fragmentation of Italian waste collection rules. Co-founder D remarked that "When we investigated the municipal waste sorting practices, we found 34 different ways, 34 different patterns of doing waste collection in Italy!". Co-founder M added: "When I stay a few days in a city, I have to learn new nomenclatures, new waste collection practices, new colors of the bins for segregating each recyclable waste material stream. Sometimes you do not even know where to find bins." With the aim of providing ready-to-use information on waste segregation for both citizens and travelers, the founders created a DP that associates the end-user's location (via mobile phones' GPS) with the municipal-level rules for sorting discarded materials and packaging.

This project required Alpha to develop a database of commercial products, which was partly crowdsourced from manufacturers, but "also (fed) by personally going around supermarkets and scanning products to record them" (Co-founder M). The initial data set of 20,000 products has since expanded to more than 1,800,000 commercial products. Citizens have contributed information for about 25% of all products by uploading product characteristics and material information through the platform.

Alpha has synchronized the product database with the waste collection and sorting rules, which are digitally sourced from municipalities and/or waste management companies and



Notes: The platform has an AI-based system that interacts with two databases: one containing information on products (DB on product) and the other on disposal rules (DB on disposal rules). Citizens can interact with the system through a user-friendly graphical user interface (citizen GUI), where they can input or access information on specific products according to local disposal rules. On the other side, there is the client GUI tailored for use by waste management companies and municipalities, allowing these stakeholders to access and manage the disposal rules

Source: Authors' own work

Figure 2. Architecture of the DP for MSW recycling

uploaded and accessed via dedicated graphical interfaces to easily query the databases. From the point of view of co-founder M: “Our platform is an ideal link that connects all the players of the world of municipal waste management, where the citizen, however, is the main actor, which not only accesses waste sorting information but also spread knowledge, thus contributing to retaining value from waste.”

In this way, the platform aims to fill two important circularity holes in the MSW system: the first represented by the missing connection between products’ manufacturers and users, and the second between product users and other recycling chain actors. To these ends, the DP centralizes all information in one single repository. That said, the DP does not involve downstream actors of the value chain, such as waste transport companies and waste recycling facilities, whose B2B relations still rely on face-to-face communication or industry meetings.

Since Alpha’s DP goal is to “facilitate and speed up communication among municipalities, waste management companies and citizens or other end-users” (as reported by co-founder D), the company started implementing an AI system in 2017 that speeds up the categorization of products and its end-of-life management. Specifically, users can upload pictures of items, even without the packaging or a barcode, and the algorithm will help in correctly sorting the waste (which also increases the accuracy of the DP’s algorithm). “This creates a win-win situation for everyone involved in the waste management process” (co-founder D), addressing a crucial challenge in the correct disposal of untagged products. Indeed, when there is a lack of information on the material composition of a product, citizens may unintentionally dispose of it incorrectly. Such mistakes can hinder the efficiency of the recovery and recycling processes, disrupting the optimal flow of resources and leading to a loss of residual value.

The most recent features added to the DP allow citizens to converse with each other and their municipalities. For instance, the DP has a notice board for the re-use of objects before they become waste. In addition, the DP now includes tools to report waste mismanagement: Citizens can notify their municipalities about illegal dumping, and more generally about environmental and sanitary problems, by simply uploading a picture with their mobile phone. Waste management companies and/or municipalities receive the alert, geolocate the complaint and react. As reported by co-founder D: “While in the past, citizens had no idea of which actor or entity to call for solving issues, now the process is automated, and all actors concerned are promptly mobilized.” Case in point: over five years (2018–2023), the number of monthly citizens’ alerts has grown from 134 to 1,824.

To optimize citizens’ involvement and ensure optimal platform functioning, the DP is free for end-users, while both municipalities and waste management companies pay a fee. The latter entities can decide which features of the DP to subscribe to, but the design of the DP is defined by Alpha “ab origine”. The DP is not currently connected to any reward mechanisms for end-users.

4.2 *Using technology to reach and engage citizens*

The interviews with waste management companies, in tandem with secondary data from sustainability reports, make clear that DPs for MSW have proliferated since 2014, propelled by the Industry 4.0 paradigm (European Commission, 2014). This “has facilitated the digitalization of companies and services” (Italian Authority for Energy and Environment, standard setter body for MSW management in Italy), but the key motivation for introducing DPs was to establish a dialogue with end-users. The waste management companies aimed at providing citizens with reliable and dynamically updated information about waste segregation. In the words of the representative of Waste Management Company A, “[...] we needed a tool that would ensure [the provision of] updated sorting rules, waste collection calendars, information on info points and collection centers opening hours, etc. and that would be connected to local MSW management system, thus guaranteeing uniformity and certainty of procedures.”

Similarly, civil servants of different municipalities emphasized the urgency of reacting to citizens’ growing information needs on changes in waste collection, sorting and recycling operations. “When door-to-door collection was introduced, we initially distributed leaflets and handbooks. However, after meeting with the waste manager, we gradually replaced them with the DP, which we consider very helpful and engaging for users” (Municipality Epsilon). This was confirmed by Waste Management Company B, which serves the Municipality Epsilon: “The user interface that allows the DP to interact with citizens is easy to use and engaging. Its usage made waste segregation more acceptable.” Engagement is easier because the DP “is installed on the smartphone, relies on pictures, and allows for interactions” – effectively leveraging gaming and social media dynamics. In addition, the app helps reach all possible end-users (i.e. not only citizens): “The app can be downloaded by everyone, even temporary visitors of an Airbnb” (Waste Management Company A).

However, the DP may have limited utility when a municipality is affected by the phenomenon of over-tourism: “Where there is a mass of tourists that do not care about sorting because they’re on vacation, engagement is really challenging; the DP does not make a great difference if there is no willingness to collaborate” (Municipality Beta). In addition, it does not seem to sufficiently foster sustainable waste management behaviors among elderly residents. As noted by Municipality Teta and echoed by Waste Management Company C: “It is certainly a valid information tool. [However], the DP must be complemented with other initiatives in some rural areas where the average age is very high.” In short, the DP seems to

be useful for informing a large swath of end-users, but may have limited value for specific categories of people constituencies as already noted by [Nastjuk et al. \(2022\)](#) with reference to elderly residents, who generally possess lower levels of digital literacy.

In addition, citizens' engagement is confined to the mere co-implementation of waste management services. Indeed, the MSW is co-initiated and co-designed by waste managers and municipalities without citizen input. As highlighted by a civil servant from Municipality Beta: "Before deciding to establish the curbside collection system, we consulted with Waste Management Company C on how to design this new service and how to inform citizens. We did not launch a public consultation to collect citizens' viewpoints on the changes that the new system would have required."

4.3 Multiple values generated from the co-creation process

The interviewees acknowledged several benefits associated with the use of DPs in general and the DP in question. According to Waste Management Company B, DPs "positively affect waste valorization related to the secondary materials market." Indeed, the better the waste sorting process, the higher the quality of recycled materials and associated revenues. In addition, the use of the DPs helps to reduce the costs of logistics operations and mandatory informative campaigns. In the words of Waste Management company A: "Given that the communication budget [in municipalities' tenders] is often set at 1 euro [per citizen], for a municipality of 15,000 residents, our expenditure is 15,000 euro yearly. However, the use of the platform allows us to reduce these costs to 10 cents per citizen." Waste Management Company B added: "After implementing the use of the DP, we decided to stop printing the waste dictionary for citizens, which had a significant cost." Meanwhile, Waste Management Company D considered the adoption of DPs as not only a means for better communication and interaction, but a strategic asset for "compliance with broader EU mandatory disclosure regulation in terms of annual recycling rates."

The DP in question also helped to minimize public health risks by not only facilitating greater operational efficiency and on-demand assistance but also notifying authorities about improper disposal practices. These are considered "important social and environmental benefits in suburban areas densely populated" (Waste Management Company A) because "instant notifications about illegal dumping enable rapid on-site assistance with minimization of negative effects related to spillage of hazardous substances and eventually identification of those responsible for the environmental damage" (Waste Management Company B).

The tangible benefits of using the DP were numerous, according to the officer for Region X: "Material positive impacts can be envisaged for those citizens living in municipalities adopting the Pay-As-You-Throw (PAYT) system." Indeed, improvements in waste sorting may decrease the nonrecyclable waste volumes, thus, reducing both compliance costs for citizens (with regard to waste tax) and logistical costs for waste management companies (in treating nonrecyclable materials in landfilling sites). This situation generates environmental and economic value, reducing negative externalities created by obsolete waste treatment processes, on one side, and spurring the secondary materials market, on the other.

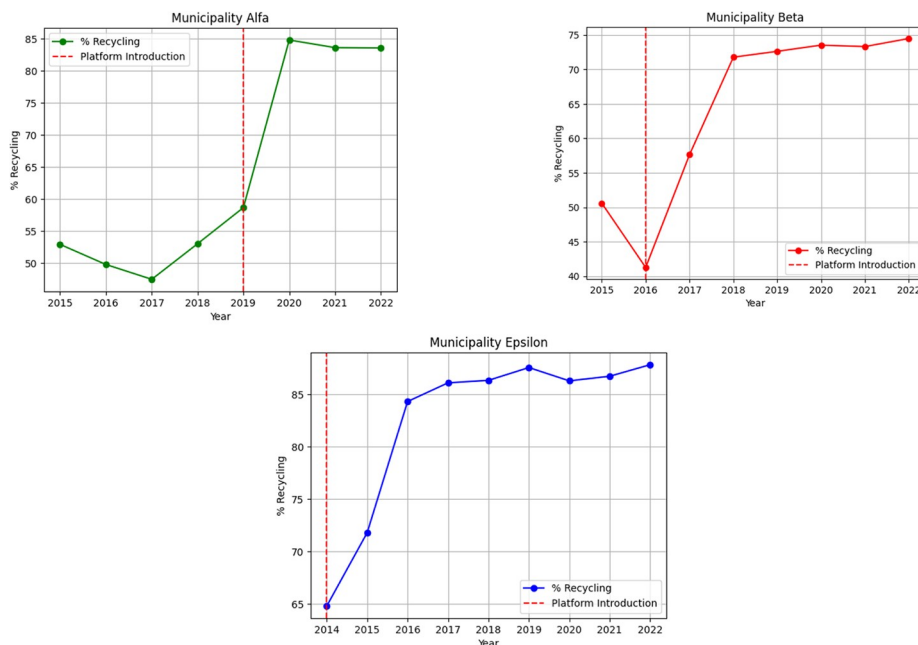
Finally, the interviews reported intangible benefits associated with the DP. Waste Management Company A highlighted that "the primary impact of DPs lies in educating citizens on improving the quality of their recycling efforts." Similarly, Waste Management Company C recalled that the DP triggered "the development of a recycling culture among citizens." For hesitant individuals, the DP provides a powerful tool for understanding and participating in waste sorting, "addressing the concerns of those who are doubtful about waste sorting at source" (Waste Management Company A), while "the use of digital

technologies and interactive elements allows [the DP] to closely involve younger generations” and promote more “sustainable practices and community participation” (Waste Management Company B). As a consequence, the use of the DP fosters “awareness, a sense of community [...] and a kind of civil responsibility towards the planet” among some citizens (Waste Management Company D).

As more citizens engage with DPs, driven by both tangible advantages and a sense of community, the more the overall culture of recycling deepens and affects actual practices – as demonstrated by the massive improvement in the recycling performance associated with the adoption of the DP (Figure 3).

5. Discussion

Consistent with the existing literature that interprets MSW management systems as networks reliant on the interconnectedness and interoperability of various processes and structures (De Souza Lima Cano *et al.*, 2022; Du Rietz, 2023), the present findings show that DPs can connect different actors of the recycling chain by informing and mobilizing end-users (e.g. citizens and even travelers). By offering a centralized repository of information that enables multiple dialogues, the DP favors knowledge sharing and integration (Sjödin, 2019), which ultimately increases efficiency in waste management (Sarc *et al.*, 2019) and generates multiple forms of value (Costa *et al.*, 2022). The use of a DP that uses barcodes, databases, GPS technologies and AI-based systems seems to effectively perform a brokerage role,



Note: The red dashed line marks the year when the DP was introduced

Source: Authors' own work on ISPra (2024) data

Figure 3. Percentage of recycling in the interviewed municipalities from 2014 to 2022

thereby closing the structural and circularity holes between citizens, municipalities and waste management companies (Ciulli *et al.*, 2020).

The present study demonstrates how four key brokerage functions – connecting, informing, mobilizing and integrating – empower an integrated MSW management system based on collaborative mechanisms and citizens’ engagement. These four functions are the most relevant and, therefore, sufficient conditions for brokering.

The DP’s user-friendly technology (Lee and Trimi, 2018) represents a key element that allows it to act as a “tertius iungens” (Ciulli *et al.*, 2020) that creates new linkages (i.e. connecting function), as well as establish a bidirectional and real-time flow of knowledge between brokered parties with complementary needs (i.e. informing function). Unlike static information found in traditional communication, DPs have the strength to continuously update and transfer information. This feature facilitates understanding and engagement among citizens, waste managers, municipalities and the platform itself (i.e. mobilizing function). Importantly, citizens’ participation and resource mobilization may take place even if there are no monetary rewards. The DP in question leveraged gaming dynamics (i.e. pictures, interactions, etc.) that generate nonmaterial rewards (e.g. an enjoyable experience and sense of recognition) to the users who performed the correct action (Landi and Russo, 2022). This form of gamification (Helmefalk and Rosenlund, 2020; Mu *et al.*, 2022) encourages citizens to segregate waste while activating learning mechanisms, in line with SDG no. 4.7 (González-Briones *et al.*, 2020). Finally, the knowledge owned by different actors is blended by the DP into a co-production program (i.e. integrating function): In this case study, municipalities, waste management companies and waste consortia populated databases with disposal rules and other relevant information for end-users; meanwhile, the citizens enriched the product databases by scanning images, notifying authorities about waste-related issues and interacting with the DP. Together, these actors integrated their knowledge to elevate the quality and effectiveness of waste recycling. Therefore, this study supports Ciulli *et al.*’s (2020) view that brokerage is a collective process rather than the traditional perspective of network studies that brokerage is conducted by a single actor (Becker and Bodin, 2022; Stovel and Shaw, 2012).

This co-creation process, empowered by the DP’s brokerage function, generates multiple values for both citizens and society (Dudau *et al.*, 2019). The economic value for waste management companies and municipalities mainly derives from the lower costs of digitally disclosing waste management practices (as suggested by Mol, 2015) and the higher efficiency in waste management operations (in line with Babaei *et al.*, 2015; Emery *et al.*, 2003; Handayani *et al.*, 2018). For the DP’s service provider, the value created is measured by the sale of the DP licenses, which are considered a cost-effective way for municipalities to promote sustainable practices among citizens. Meanwhile, DPs also generate positive environmental outcomes (Landi and Russo, 2022; Lanzalonga *et al.*, 2024) and contribute to the achievement of CE and SDGs and targets (Helmefalk and Rosenlund, 2020; Mu *et al.*, 2022). Finally, DPs produce relevant societal values, which are often perceived as intangible. Echoing Kurniawan *et al.* (2022) and Paletta (2019), this case study suggests that DPs can reduce social health risks by actively involving citizens in reporting urban littering and illegal dumping. More generally, knowledge-sharing creates broader citizen awareness about the potential of a well-functioning MSW system. Awareness and a culture of recycling then lead to greater environmental benefits, such as the maximization of material recovery in newer production cycles and a reduction in landfill usage and environment degradation. In short, there seems to be a symbiotic relationship between waste management companies’ economic effectiveness and citizens’ environmental stewardship and loyalty (Iacovidou *et al.*, 2017; Urbinati *et al.*, 2017).

While service management literature often assumes that the value created is appropriated by the service provider (Vargo and Lusch, 2004), the findings show that also citizens and other stakeholders receive benefits, as advocated by the public management literature (Osborne *et al.*, 2016). Following the work of Lanzalunga *et al.* (2024), one can argue that the adoption of digital solutions supporting PAYT schemes may be the ideal solution for municipalities, as they can increase the recycling rate (in line with SDG no. 12.5.1) and the revenues available for sanitation-related activities (i.e. from selling higher-quality recycled materials), while lowering the waste tax rate asked of citizens. Therefore, the DP can be considered both economically feasible and socially legitimate (Dijkgraaf *et al.*, 2003; Park and Moon, 2023).

That said, there are notable barriers to implementing DPs, such as citizens' digital literacy and the accessibility of this and other internet technologies. Echoing the public management literature on digital public services (Meijer and Boon, 2021; Petrescu, 2019; Yu *et al.*, 2019), this case study shows that the use of DPs in waste management introduces numerous advantages, such as enhanced sorting and information dissemination, while also exposing the struggles of older or less tech-savvy segments to use said DPs effectively (Kalašová *et al.*, 2021). The consequences of this "digital divide" – where a section of the population, lacking in either access to or the skills to use a technology, finds itself excluded from its benefits (Dutta and Sarma, 2020) – are particularly pronounced in light of the smart cities paradigm (Dameri *et al.*, 2019; Trombin *et al.*, 2020). Indeed, cities are increasingly adopting platformization as a business model to foster value co-creation among stakeholders with diverse interests (Pencarelli *et al.*, 2018; Yao and Miao, 2021).

Another critical issue that emerged from the case study is the lack of citizens of involvement in co-designing the DP, revealing the existence of an unaddressed structural hole. According to Torfing *et al.* (2021), co-creating public value involves a broad group of actors collaborating to co-design innovative solutions for societal problems – representing a significant departure from traditional government-centric idea generation. However, in this case study the DP was designed by the platform owner and its features were embedded within the MSW management service previously structured by waste management companies and municipalities. Consequently, the citizen/end-user was excluded from the service co-design phase and merely served as a co-implementer in the co-production of the service (Voorberg *et al.*, 2015). Waste management companies, municipalities and DP service providers are missing the opportunity to involve citizens in the development of effective solutions and societal value, as they continue considering citizens as mere co-implementers (Landi and Russo, 2022), while Public Management scholars are increasingly highlighting the potential of adopting more inclusive approaches for public service design and delivery in the digital age (Barbera *et al.*, 2024; Garnett and Cooper, 2014; OECD, 2022; Osborne *et al.*, 2022).

6. Conclusion

This study aimed to explore how DPs can address actors' fragmentation and scarce citizen engagement in MSW management systems (De Souza Lima Cano *et al.*, 2022; Du Rietz, 2023). Drawing from network theory and the concept of value co-creation, the case study focused on how DPs contribute to knowledge-sharing and cooperation mechanisms, which ultimately favors co-production and co-creation processes. The results show that DPs play a brokerage role that addresses both structural and circularity holes (Ciulli *et al.*, 2020), while galvanizing the creation of joint economic, social and environmental values. Therefore, the study indicates that DPs can enhance public services in the waste recycling domain, in line with sustainability ambitions (González-Briones *et al.*, 2020).

However, such results hinge on DPs' ability to engage and mobilize citizens, who represent an essential node in the recycling value chain. As the case study demonstrated, DPs can deliver tangible and intangible benefits to various stakeholders when the platforms conceive citizens and end-users not as mere receivers of the MSW service but as active co-implementers in its delivery. Notably, the benefits can occur even if some actors in the recycling value chain (e.g. transport companies) are not connected. Furthermore, DPs do not necessarily need to implement monetary reward mechanisms to engage end-users so long as they satisfy citizens' information needs and aspirations to actively contribute to a more sustainable planet.

Compared to previous research, this study diverges from public management literature that views services as outputs produced by PSOs, as it acknowledges that public services depend on many actors and not only PSOs and final users. It is closer to the recent concept of public service ecosystems (Trischler and Charles, 2019; Osborne *et al.*, 2022), but it also critiques its prevailing assumption that actors within these ecosystems can be easily connected (Vasconcelos *et al.*, 2022). Instead, and following Ciulli *et al.* (2020), it demonstrates the existence of structural and circularity holes in the recycling value chain that DPs can address.

Thus, the case analysis contributes to the debate on value co-creation within public management literature by questioning its underlying assumption about inherent interconnections among actors within public service ecosystems (Osborne *et al.*, 2022; Petrescu, 2019). It reveals that such interconnections cannot be taken for granted in contexts where reforms inspired by New Public Management introduced a quasi-market approach to the public sector (Citroni *et al.*, 2016; Kuhlmann, 2010). Consequently, brokers, like DPs, are essential to facilitate the development of these connections, especially with citizens (Kurniawan *et al.*, 2022). In addition, by moving beyond technical analyses of digital solutions (Cohen and Gil, 2021), this study explores how DPs meet citizens' mounting accountability expectations for waste management, which is no longer solely relegated to plant engineering, but increasingly relies on citizens through separation at source.

Given that citizens actively seek information and are willing to cooperate via DPs, the case study shows the importance of positioning citizens as active co-implementers of waste valorization routes rather than merely as waste generators (De Souza Lima Cano *et al.*, 2022). Relatedly, this study encourages researchers to clearly distinguish between co-creation and co-production in the public service domain: The two terms cannot be used interchangeably because the former entails the involvement of citizens in the design phase of public services, whereas the latter regards service delivery only. Indeed, citizens' involvement in strategic decision-making, which occurs in the design phase, is a missing element in the previous literature on MSW management (Jørgensen *et al.*, 2023) that deserves attention. Citizens are increasingly responsible for waste segregation, but that demand is not being repaid with appropriate public participation in strategic decision-making.

That said, the present research offers several policy implications for the relevant stakeholders. First, citizens' digital literacy raises concerns about DPs' effectiveness. Municipalities and waste management companies have to consider the "digital divide" that characterizes several segments of the population, who could be excluded from accessing a public service like MSW management. To this end, policymakers should seek to implement strategies, in line with the Society 5.0 paradigm (De Felice *et al.*, 2021), that emphasize a human-centered approach to technology which, in the public management literature, is translated in user-focused public services (Osborne *et al.*, 2022). Promoting up-skill and re-

skill programs and doing focus testing with different categories of users would help ensure that DPs are accessible and user-friendly for all demographics.

Second, considering that flax-tax systems are prevalent in most EU countries (Agovino *et al.*, 2021), municipalities should start considering the use of PAYT schemes together with DPs as they can significantly enhance waste recycling. DPs can help reduce littering, improve the accuracy of waste separation at the source (Lanzalunga *et al.*, 2024) and be integrated with systems that measure recycling performance. That information can then be used to optimize waste governance mechanisms and adjust waste tax rates for citizens. This approach not only helps reduce inequality in taxation among different municipalities but also creates economic value for both households and local governments by ensuring more equitable and efficient MSW systems.

Finally, PSOs and waste consortia might consider the possibility of incentivizing or enforcing the adoption of DPs by municipalities and waste management companies. The underlying rationale is that DPs generate not only direct network effects (i.e. a higher total number of end-users leads to a greater recycling culture and better recycling rates), but also indirect ones (Fu *et al.*, 2021). The latter occur when one group of users (e.g. waste management companies and municipalities) integrate the DP into their operations and effectively make the platform mandatory for another group of users (e.g. citizens) (Nooren *et al.*, 2018). This increases the overall number of participants and expands the DP's impact on MSW management practices. Eventually, the diffusion of socially accepted procedures and habits contributes to higher national recycling rates and the fulfilment of SDGs.

Of course, this study features limitations that may inspire future research. First, the case analysis focused on Italy. Scholars should conduct comparative studies in different geographic and socio-economic contexts to add generality and nuance to this study's insights. For instance, future studies could focus on countries characterized by a massive "digital divide" to understand its implications for waste management systems (Dameri *et al.*, 2019; Trombin *et al.*, 2020). Second, this study did not consider the synergistic potential of combining DPs with other emerging technologies (e.g. blockchain and Internet of Things) (De Villiers *et al.*, 2021). Future studies could investigate these possibilities and perhaps uncover new pathways for enhancing efficiency and transparency in MSW management.

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