Involving consumers and households in smart waste recycling

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Abstract:

Smart enabling technologies such as the Big Data analytics, Internet of Things (IoT) and artificial intelligence (AI) can be used to make waste recycling more effective and sustainable in the smart city context. However, despite the technological enablers, the success of waste recycling in households is highly dependent on sustainable consumer behavior and green thinking. This paper investigates how enabling technologies can assist consumers to improve their recycling activity and overcome the barriers of efficient waste recycling. By using the Industry 5.0 paradigm as a framework, the research is conducted in terms of two qualitative case studies focusing on waste management companies and consumers, both operating in the smart city context. The results show that the smart enabling technologies can be employed not only as technical facilitators but also as motivators for efficient waste recycling on the household level. The technologies also provide tools for active participation and continuous connectivity between consumers and recycling service providers, which in turn makes it possible to involve consumers as innovators in the development of new services in smart cities.

Keywords: circular economy, waste, recycling, consumer involvement, smart city, Industry 5.0.

INTRODUCTION

Smart cities play a central role in taking steps towards sustainable development. The smart cities integrate cyberinfrastructure aiming at economic growth, better quality of life and more effective and sustainable management of resources (Roccasalva, 2022; Zhang *et al.*, 2019). At the same time, the growth in the volume of waste produced by household and businesses cause concerns to cities and regions, where the practices and operations of waste management have often proved to be ineffective. Thus, the recycling practices of households and businesses are central in the development of effective circular economy in urban areas (Castellano *et al.*, 2019). This also has clear implications to the business sector in smart cities. ICT-enhanced smart services developed by business sector actors in smart cities can greatly contribute to the efficiency of smart recycling practices, and in this manner also to the smart circular economy.

As a part of smart city development, different kinds of smart enabling technologies, such as Big Data analytics, Internet-of-Things (IoT) and Artificial Intelligence (AI) have been introduced (Esmaeilian *et al.*, 2018; Visvizi and Lytras, 2019). These technologies are expected to make a remarkable impact on cities of the future, as a part of smart city development. Previous research has suggested various definitions for a smart city (Albino *et al.*, 2015; Saeedi *et al.*, 2023; Visvizi and Lytras, 2019). From a sustainability viewpoint Caragliu et al. (2011) suggest that "a city is designated as smart if it balances economic, social, and environmental development, and if it links up to democratic processes through a participatory government". Thus, a city is considered to be smart when it aims to invest in cyber-infrastructure to foster sustainable economic growth, better quality of life and efficient management of natural resources (Caragliu *et al.*, 2011). In smart cities and circular economy context it is reasonable to expect that enabling technologies and policy goals converge in promoting increased household participation in waste recycling (Saeedi *et al.*, 2023).

During the last decade, the Industry 4.0 framework has become the overarching design paradigm for the development of digitalization in industry, and has also had a strong impact on smart city development (Ruohomaa *et al.*, 2019). To complement and gradually replace this paradigm, a new paradigm, Industry 5.0, appeared recently to promote sustainable development goals such as human-centricity, socioenvironmental

sustainability, and resilience (Ghobakhloo *et al.*, 2022; Grabowska *et al.*, 2022; Rosemann *et al.*, 2021). Industry 5.0 has also had a certain impact on smart city development. "City 5.0" (Rosemann *et al.*, 2021) aims to remodel city structures, systems and processes in a consumer-centric manner.

Waste management should be based on the principles of sustainability, and the concepts of smart city development can provide enabling technologies for this approach (Esmaeilian *et al.*, 2018; Saeedi *et al.*, 2023). IoT and AI-based tools and technologies may assist urban waste management practices, including waste collection, segregation, transportation, treatment, and final disposal (Shukla and Hait, 2022). Enabling technologies also help to monitor truck or trash bin load status, optimize truck routes, and to fine-tune the collection schedule, by using dynamic models (Esmaeilian *et al.*, 2018; Järvenpää, Jussila, Honkasaari, *et al.*, 2023; Zhang *et al.*, 2019). Thus, the previous research in smart waste management mainly focused on the enabling technologies (Chen, 2022; Esmaeilian *et al.*, 2018; Shukla and Hait, 2022), whereas the work related to the role of consumers and households in this area has received significantly less attention. Despite the technological development in enabling technologies related to smart waste management, the success of waste reduction and the recycling rate is highly dependent on sustainable consumer behavior and green thinking (Concari *et al.*, 2022; Wang *et al.*, 2019). Households' recycling activity depends on the waste fraction, as paper and plastics are recycled more often than metal and glass (Saeedi *et al.*, 2023). This, in turn, is directly linked to the acceptability of the recycling services among the consumers (Keramitsoglou and Tsagarakis, 2013). Thus, to achieve a high waste recycling rate, individual consumers and households are in the key role of facilitating material recycling (Tseng *et al.*, 2018). However, the processes cannot work without effective organization of recycling services. For this reason, there is a need for new understanding of how the enabling technologies specific to the smart city context may contribute to the improvement of consumers' recycling activity and reduce the barriers of effective recycling. This study aims to fill this gap by finding answers to the research question: *How can enabling technologies assist consumers and households to improve their recycling activity and overcome the barriers of recycling?* This question is addressed in this paper by using two qualitative case studies focusing on the involvement of consumers and households in the development of smart recycling services. The rest of this chapter is organized as follows. Section 2 presents an overview of the previous research conducted in smart recycling, focusing particularly on the role of individual consumers. As a framework, the chapter uses Industry 5.0 that has strong links to the smart city paradigm. Section 3 presents the qualitative case study methodology that is applied in the empirical part of the chapter. In section 4, the results of two case studies are presented, and their outcomes are discussed in section 5. Chapter 6 summarizes the final conclusions of the chapter.

CONSUMER INVOLVEMENT IN RECYCLING

From Industry 4.0 to Industry 5.0

During the last decade, the Industry 4.0 framework has become the overarching design paradigm for the development of digitalization in industry. In the context of smart production, Industry 4.0 represents an environment of digital technologies including robotics, Internet of Things (IoT), advanced manufacturing, and data analytics facilitate a highly flexible production environment (Rosemann *et al.*, 2021). Although Industry 4.0 has widely been seen as the "industrial revolution" of the digital age, its impacts are still largely invisible from the viewpoint of a citizen. Even though its main benefits include new levels of cost-effectiveness in a production system and previously unseen production flexibility, the products and other industrial outcomes themselves are in most cases not fundamentally impacted by Industry 4.0 (Rosemann *et al.*, 2021). A new industrial paradigm, Industry 5.0, appeared recently to complement and replace Industry 4.0. This new paradigm has the potential to move beyond the profit-centered productivity of Industry 4.0 and to promote sustainable development goals such as human-centricity, socioenvironmental sustainability, and resilience (Ghobakhloo *et al.*, 2022). In this manner, Industry 5.0 represents a transformative model that draws on Industry 4.0 to develop a data-driven industrial ecosystem that is built on the goals of sustainable development (Javaid and Haleem, 2020). Following the European Commission's 2022 Industry 5.0 agenda, the objectives for sustainable development in Industry 5.0 include the inclusive development of economic, environmental, and social pillars of sustainability and their underlying micro-objectives (Renda *et al.*, 2022).

This all contributes to the promotion of resilience, socio-environmental sustainability, and human-centricity under the sustainable development agenda (Grabowska *et al.*, 2022).

While companies still widely strive to implement different areas of Industry 4.0, the academic and professional discourse has extended to the paradigm of Industry 5.0 (Rosemann *et al.*, 2021). One central difference in these design paradigms is the shift from smart production to smart consumption. While the focus of Industry 4.0 was on production, Industry 5.0 concentrates on the time and the experiences during the consumption of a product (Ghobakhloo *et al.*, 2022), with a special emphasis on sustainability and human centricity (Zizic *et al.*, 2022). This expansion from smart production to smart consumption is facilitated by "continuous connectivity" between providers and consumers, which in turn requires digital enablers such as smart sensors, cloud computing (Rosemann *et al.*, 2021) and Big Data analytics (Järvenpää, Jussila and Kunttu, 2023; Järvenpää, Jussila, Honkasaari, *et al.*, 2023).

Consumers and households as innovators in a smart city context

The smart city concept is derived from the intersection of studies in urbanism and information and communication technology (ICT), combined with the dimensions of creativity and humanity (Viale Pereira *et al.*, 2017) In this manner, the concept of smart city represents new ways of organizing city functions and urban life for environmental purposes, based on digitalization (Rosemann *et al.*, 2021). The ever-increasing transition towards smarter cities involves changing and evolving stakeholder roles (Ruohomaa *et al.*, 2019). Citizens are not considered as passive users, but instead they are seen as active stakeholders who can act as participants, collaborators and developers in their own networks and communities (Caragliu *et al.*, 2011). Similarly, technology is no longer seen as an asset but as an enabler of continuous development. Moreover, smart city framework does not see business as a provider but rather as a collaboration partner. It is also essential to understand that the smart city development does not mean merely developing and providing new digital services for citizens. Instead, it is a transformative process that involves city structures, governance and functions. The process is highly interactive and collaborative, and it should involve all relevant stakeholders in the cities (Vanolo, 2014).

As indicated in the newest OECD Oslo Manual (OECD/Eurostat, 2018) on innovation measurement and policy, households and private consumers play a central role in the current, evolving innovation environment (Kunttu *et al.*, 2021). We define consumer as a person who purchases a product or service for his/her own need and uses or consumes it. In this manner, households can be seen as represent groups of individual consumers. Digitalization enables collaborative learning and the co-creation of new, innovative solutions by consumers and their informal communities. This means that involving the consumers, users and other target groups of collaborative networks (Diercks *et al.*, 2019) is increasingly important for service provides and product manufacturers. The innovation networks may include a wide variety of actors, such as entrepreneurs, non-profit organizations, cities, users, and private citizens. The linkages between the actors can constitute feedback loops that interact with one another (Kunttu *et al.*, 2021). The outcomes of the free innovation activities of users can be commercialized through the business partners or the user entrepreneurs (Radu and Voda, 2022), or the user communities may choose to share their innovations freely (von Hippel, 2017). This is all directly related to active and participative citizenship in the smart city context, where sustainable lifestyle with greener and safer urban environment in the cities is expected to provide a variety of essential services, in which sustainability plays an increasingly important role. A smart city concept inspired by the Industry 5.0 standard, "City 5.0" is defined as a "*liveable city that is (re)modeled with the aim of eliminating restrictions for its citizens by using digitalization for the provision of public goods and services*" Rosemann et al. (2021, p. 73). In this concept, digital technologies play a central role as facilitators of new services. However, whereas technology was at the center of the provider-centric thinking of smart cities, the new consumer-centric approach of City 5.0 requires re-modeling the structures related to city structures, systems, and processes.

Consumers' Recycling Behavior

Recycling is a fundamental part of the circular economy (Murray *et al.*, 2017). The more materials can be recycled, the more sustainable the production processes that can be achieved. Recycling at the household level is justified by four main points (Martin *et al.*, 2006): 1) It reduces the demand of virgin raw materials; 2) There are generally fewer environmental impacts from material extraction, processing and transportation; 3) Products made from recyclables rather than virgin materials generally consume less energy in manufacturing; and 4) Lower down the hierarchy, less waste is disposed of by the more environmentally damaging methods.

Waste sorting at source refers to the classification of waste by general materials or separate collection by waste groups (Rousta and Bolton, 2019). The households are expected to carry different waste types to different containers provided in the premises or in the separate recycling points. Saeedi et al. (2023) studied the households' propensity to engage in segregation, orderly disposal and recycling of household solid waste. The results show that recycling behaviour of individuals at home separates from waste generated by these same individuals in public venues such as shopping malls and offices. The success of waste reduction and recycling rate is highly dependent on sustainable consumer behavior (Esmaeilian *et al.*, 2018). During the last two decades, citizens' recycling behavior has become an important area of investigation in numerous disciplines. This topic has received relatively plentiful research interest for several reasons, including the depletion of natural resources, the challenges in correctly handling waste, the complexity of human behavior, and the influence of media (Concari *et al.*, 2022). The role of consumers, and the households' contributions to recycling activities has been found to be particularly significant. For example, Tseng et al. (2018) have concluded that "human behavior is a strategic domain because of the enduring effects of both poor and good recycling habits". Thus, to achieve a high waste recycling rate, individual citizens and households are in the key role in facilitating material recycling, but the processes cannot work without effective organization of recycling services. Previous literature has recognized some typical barriers for waste recycling on the household level. Those include resistance from attitudes, the quality of the recycling services, and problems arising from culture (Chu and Chiu, 2003). Scholars (e.g., Concari et al., 2022) have suggested that technological advancements may be able to influence recycling behavior. Consequently, smart waste management (Zhang *et al.*, 2019) has become a central part of sustainability development in the smart city context. Moreover, the introduction of digital technologies in waste management and material recycling requires major changes in waste management processes since they can enable a connection between the citizens and the provider of recycling services. This all requires establishment and maintenance of a close interaction between the service providers and the citizen to increase the acceptability of waste recycling among consumers (Keramitsoglou and Tsagarakis, 2013).

METHODS

The empirical part of the paper consists of two case studies. The first case study investigated the role of consumers and households in waste recycling by interviewing the managers of companies operating in waste management and material recycling. The second case studied consumers' perceptions of the possibilities of assisting technologies in supporting end-of-life text recycling by means of a consumer survey.

Table 1 Interviewed organizations

Case	Title of interviewee	Business area	Number of households in operational area	Number of employees
A	CEO	Municipal waste management	70 000	60
B	CDO	Municipal waste management	200 000	90

C	CEO	Privately owned waste management	20 000	50
D	CEO	Consultant	not applicable	>5
E	Development Manager	Regional Development Organization	not applicable	not applicable

RESULTS

Case 1: Consumers' role in developing recycling and waste management services

In the first case study, we focused on the role of citizens and households in recycling. The goal of the data collection in this case study was to understand the role of the users and households in developing recycling services and how companies have involved their users in the development of recycling services. We also investigated how enabling technologies could help households increase their recycling activity.
The case companies involved in the case study provide recycling and waste management services for consumers as well as for business, as summarized in Table 1. The research data was collected in two phases. In the first phase, the company managers were interviewed separately in the preliminary data collection round conducted in the first part of 2022. The purpose of this first round was to understand the companies' operations, business logic and development needs in material recycling. The preliminary results were then analyzed by researchers, and the remainder of the data was collected via additional interviews. Based on the collected data, the researchers created a semi-structured group interview template that focused on three specific topics. The topics were: 1) Barriers for efficient waste sorting in households, 2) Means to improve consumers' recycling behavior through inclusive planning and service design, and 3) The possibilities of digital enabling technologies as motivators for household recycling. The group interview was conducted for the case companies in November 2022; it was recorded and transcribed.

Barriers to efficient waste sorting in households

The typical waste types collected separately in Finland include at least biowaste, paper, cardboard, glass, metals, and plastic containers. The mixed waste that does not belong to any of these types is collected for energy use. For all these waste types, there are separate collection and recycling processes. For example, biowaste is valuable raw material for renewable fuel (biogas) and fertilizers, whereas waste paper, cardboard, glass, metals and plastic can be used to produce recycled products. However, recent regular studies carried out by the waste management companies indicate that 20-40% of mixed waste still contains organic materials that should have been sorted into the container for biowaste. In a similar manner, the mixed waste contains many other waste types that should have been sorted into other containers. This indicates that waste sorting at source (Rousta and Bolton, 2019) in the households is still a major challenge for efficient material recycling, and too few households still sort their waste in the correct manner.

> *"Everything depends on the waste sorting at source. Improving consumers' waste sorting activity is key to efficient recycling." Case C*

> *"Why do people act like they do? We know that some people always separate waste and recycle, but some people still just throw everything into mixed waste without doing any sorting." Case B*

All the interviewed company representatives agreed that the user point of view is important in waste management and recycling, as waste sorting at source is seen as the best way so far to separate materials

for recycling (Rousta and Bolton, 2019). This means that consumers should separate their waste at home in different bins. Currently, a common practice for the service providers is to bring the waste containers as near as possible to the households to get people to use the service. However, this seems to not be enough to motivate all consumers to sort their waste.

> *"So far, waste sorting at source has proven to be the best way to separate materials. The fact that it does not work very well is probably due to engineering thinking." Case B*

The interviewees indicated that the waste management and recycling sector traditionally runs on an engineering type of thinking in the design and implementation of the services. This, in turn, emphasizes the need to apply a more user-centric approach in the service design (Kunttu & Neuvo, 2020). Thus, the interviewees agreed that understanding the consumers' recycling behavior would be important for improving their understanding of how consumers can be activated and involved, and why they behave like they do:

> *"Sometimes the planning is governed by the waste act and the engineers, and there is no room for humans." Case B*

> *"This sector is still very engineering-minded in its attitude, and I think it would be appropriate to think from a behavioral point of view. Even if it seems that people are ruining all the fine systems by putting the wrong waste in the wrong place, there is, of course, a reason for them to do so. I believe that we should look into what can be done to ensure that the consumer is better involved." Case A*

> *"Our current customer satisfaction surveys do not give relevant input to development – it should be done through behavioral science." Case B*

The outcomes of the interview supports the previous literature in suggesting that the success of waste reduction and the rate of recycling is highly dependent on consumers' recycling behavior (Concari *et al.*, 2022; Wang *et al.*, 2019), and the consumers and households play a central role in facilitating material recycling (Tseng *et al.*, 2018).

Improving the consumers' recycling behavior through inclusive planning and service design

The interviewees were asked how they try to understand the wishes and needs of households. On a general level, the interviewees referred to the customer satisfaction surveys that they make for their customers each year. According to these surveys, the household customers seem to be relatively satisfied with the waste management and recycling services that are available. However, the interviewee responses were quite coherent in indicating that the surveys typically provide very few development ideas from the customers. Thus, collecting and analyzing the ideas from the household customers was seen as a major challenge for the waste management companies:

> *"The consumers' input and ideas do not currently have remarkable input in our development work." Case A*

> *"The consumers would definitely be able to give valuable ideas to us regarding the usability and accessibility of recycling services." Case B*

However, these companies see that the users would have something to say for usability and accessibility of waste management and recycling services. This, in turn, would facilitate the acceptability of the recycling services among the consumers and thus encourage them to sort their waste more efficiently (Keramitsoglou and Tsagarakis, 2013).

”We need to get people to see the benefits of waste separation.” Case B

”If you don’t know why waste is separated, it’s easy to put all the waste in one bag and throw it in the mixed waste container.” Case C

In the interviews, the participants indicated that one of the most essential obstacles for motivating households to sort their waste at the source was the fact that they do not get any feedback on their recycling. It is seen as important to provide feedback on the recycling rate to increase consumers’ and households’ motivation to pay attention to sorting their waste. This could be motivated by green thinking among the users of recycling services (Esmaeilian *et al.*, 2018; Shukla and Hait, 2022). Thus, waste separation should be justified for consumers by contribution to the reduction of virgin materials used in production of new products and reduced environmental impact (Martin *et al.*, 2006).

”We should be able to communicate the benefits of waste recycling to household customers more clearly. For this, we could use waste collection data.” Case B

“The consumers could be more motivated to recycle their waste if they were provided with the information on the results of recycling.” Case C

The interviewees agreed that the acceptability of the waste sorting in households could probably be improved if the consumers could receive up-to-date information on the waste recycling results, as suggested in, e.g., Keramitsoglou et al. (2013).

Digital enabling technologies as motivators for household recycling

The interview data showed that it is important to provide feedback for residents and housing companies to inform them how they perform and what their impact is on recycling and source separation rates. Without the feedback and understanding it provides, it is very easy to quit source separation and recycling, and just deliver all of one’s discarded materials to the mixed waste container.

”A campaign is needed to show the amount collected in the area as well as the gap towards the target. It is also important to activate young people, to raise their awareness and involve them in recycling.” Case E

“The first step in digitalization could be to provide visibility for consumers to their own performance.” Case B

Among the interviewees, gamification was considered to be one potential way to motivate households:

”It is technically possible to measure the amounts of certain waste types per household in certain areas. For example, we can compare the households’ activity to sort their biowaste in different regions. In this way, regions of active recycling could be rewarded for their recycling performance.” Case A

Again, making the amounts of recycled materials visible to the consumers was considered important. This also enables incentivization of households for their waste recycling (Fontecha *et al.*, 2022). Waste management companies already collect several kinds of data, even though they do not necessarily utilize it (Järvenpää, Jussila and Kunttu, 2023). One of the interviewed companies mentioned that their current data collection practices in biowaste collection enable data sharing with consumers, which makes it possible to compare their own performance with others.

"*We measure the filling rate of containers in the biowaste collection, but we have not utilized the accumulated data and shared it with customers." Case A*

"Pricing via the pay-as-you-throw principle, meaning that the more you recycle, the less you pay for waste management services." Case A

A conclusion from the group interview was that as data is currently available to measure the amounts of the biowaste collected from certain areas, it would also be technically possible to provide incentives to the households based on their recycling activity.

Case 2: Need for assisting technologies for the recycling of the end-of-life textiles

In the second case study, the goal was to improve understanding of the consumers' perceptions on the possibilities of assisting technologies in supporting end-of-life text recycling. A survey of 43 consumers in the operational area of one municipal waste management company was conducted in December 2022. The aim was to find out what the role of the user is in developing recycling and waste management services and how technology could improve recycling. In the survey, the questions inquired whether the recipients had personally recycled end-of-life textiles, how they perceived technology could assist the practice of end-of-life textile recycling and how technology could remove some of the challenges perceived in end-of-life textile recycling. The general results of the survey showed that 26 respondents (62%) had taken end-of-life-textiles to a collection point. The survey results also showed that the consumers wished for more collection points (11) and information about their location as well as sorting instructions. Regarding the consumers' input and ideas related to the assistive technologies in end-of-life textile recycling, there were four main areas of outcome from the textile recycling survey.

Information on the collection point location and filling rate

The survey showed that consumers need information on what exactly is accepted for end-of-life textile recycling. Municipal waste management companies have learned from practice that even when there are vast instructions at their collection points at waste stations and on websites, consumers do not have time to read them. Thus, according to the survey, the consumers consider that they would benefit from the information campaign in different media. This, together with technical solutions to assist textile waste sorting, would probably increase the acceptability of the provided recycling services (Fontecha *et al.*, 2022). The survey respondents also suggested several types of technical enablers, such as QR codes, that would help them to obtain detailed information about certain recycling points or textile items.

"More collection points, e.g., in shopping centers and store lobbies, like bottle return."

"First of all, there should be more collection points for end-of-life-textiles. If the technology would recognize the elements that are not suitable items, it would probably lower the threshold for retuning end-of-life-textiles."

"Information on collection points and textile recycling could be more visible in media that consumers follow. Maybe the YouTubers could add visibility for end-of-life-textile recycling."

Respondents suggested that a mobile application would be useful for consumers to find the nearest collection point and show what the suitable items are that can be brought to the collection point. However, as consumers already have plenty of applications on their mobile phones, they are not necessarily keen to install new applications.

"I have never thought that I could recycle textiles. However, we would have quite a lot of discarded textiles, so it would be nice to know how and where I can take the textiles. It's hard

to say how it could be easier when I haven't taken things to the collection point, but maybe I wouldn't be interested in downloading an application either, at least when there are already a hundred of them. The pages looked very informative. Maybe there could be a search function for the nearest collection point and a quick guide for sorting clearly on one page. I don't see any sensors or tags for consumers, because removal textiles are not a weekly issue."

According to the survey, the consumers seem to appreciate online information on the filling status of the end-of-life textile collection points, since they feel that it is important to be sure there is still room in collection containers when they go there to dispose of their end-of-life textiles. Thus, a mobile application or a website would not only show the location of collection points, but also the filling rate in real time and information on the timepoint when the container will be emptied.

"Location of the sorting points and the filling rates or emptying dates can be acquired and transmitted with the help of technology - no overfilling or unnecessary trips to a collection point that is already full (minimizing the temptation to sort incorrectly or not to sort)."

"Sometimes the collection point is full. It would be good to see the fill rate of the collection points on my mobile phone."

Assisting technologies for end-of-life textile sorting

The respondents also felt that consumers should be provided more precise instructions on what is or isn't a suitable item for the end-of-life-textile collection. Several respondents (5) also suggested automated sorting, where the collected textiles would be automatically sorted into acceptable and non-acceptable categories after collection:

"The everyday opportunities created by technology as an application or a device at a recycling point to assist the consumer in sorting and to demonstrate the recycling process of end-of-life-textiles."

"Digital assistance would be helpful to inform people why this is done and what kind of products are created from the material."

It should also be beneficial to employ AI-based methods to provide assistance for the consumers concerning the recyclability of specific textile items. Technical solutions such as AI-assisted end-of-life textile sorting machines could aid consumers and also encourage them to sort their waste for recycling correctly. Thus, technical solutions for smart recycling (Esmaeilian *et al.*, 2018; Shukla and Hait, 2022; Zhang *et al.*, 2019) could also facilitate more efficient material recycling in the case of textiles. New practices can emerge – for business, for end-of-life textile recycling as a service and for machine vision capabilities in identifying and sorting textile items.

Feedback and rewards from the recycling performance

The survey also showed that consumers are interested in getting feedback on their recycling performance, and they would be interested to have some kind of a rewarding system in a similar manner as they currently obtain some amount of money when they currently return empty bottles and cans to the shops:

"A digital tracking system would be good to inform people about the activities at the recycling point and the further processing of the collected discarded textiles. Tracking information could work as an incentive, either at a collection point or online, to encourage sensible and correct choices from the point of view of recycling."

"A fun reward system is needed".

This finding is line with those obtained in case 1 suggesting that incentivization would positively affect consumers' recycling activity (Fontecha *et al.*, 2022).

To summarize the survey results in case 2, we recognized five categories of responses that emerged from the data. The responses addressed the recycling points of the end-of-life textiles, information about end-of-life textiles, applications that could support recycling, other technical solutions and new practices that could make end-of-life textiles easier. A summary of consumers' suggestions to the four latter categories is outlined in Table 2.

Table 2 A summary of the consumers' suggestions.

Information	Applications	Other technical solutions	New practices
- What is included in end-of-life textiles and what is not?	- Mobile app or device on the recycling point that allows the check of what can be included and excluded	- Machine that handles automatic separation of end-of-life textiles and waste	- Companies supplying professional clothing to offer end-of-life textile recycling as a service
- Where are the recycling points located?	- Website or app including locations of recycling points and fill rates to avoid overfill and unnecessary trips.	- Introduction of textile deposit system, similar to beverage packages	- Textile to include "DNA" that can be used by machine vision or AI to determine the recyclability and condition of the textiles
- Questions and answers regarding what can be included in the end-of-life textiles, e.g., can there be buttons, a zipper, etc.?	- Real-time information on website or app that displays when the recycling point will be emptied the next time.	- Some kind of reward or gamification system	- Pop-up end-of-life textile recycling containers or drawers where to drop textiles, e.g., inside supermarkets, post offices or other public places
- Systematic announcements about what end-of-life textiles are in social media, television and radio campaigns	- Interactive AI guide that responds to where the particular material or waste can be recycled.	- QR code to get further information on what can be recycled from recycling points or textiles themselves	- Bring home container/bin for end-of-life textile that you stack with other waste materials (e.g., glass, plastics, etc.)

Table 2. Consumers' information needs related to textile recycling recognized in case 2 as well as technical enablers and new practices that address them.

DISCUSSION

The previous literature (e.g. Concari *et al.*, 2022) suggests that technological advances may be able to influence recycling behavior in the years to come. Smart enabling technologies such as the IoT and AI can aid in a transformation of waste management to better support the processes of circular economy. This is able to bring clear benefits not only to environment but also to the business sector in terms of effective circulation of materials, smart service development opportunities to waste management as well as new sustainable business models for business actors operating in the field of circular economy (Esmaeilian *et al.*, 2018; Roccasalva, 2022; Saeedi *et al.*, 2023). Consequently, smart waste management (Zhang *et al.*, 2019) has become a central part of sustainable development in the smart city context.

This study has investigated how the enabling technologies used in the smart city context could assist consumers to actively carry out sorting in the households, and on the other hand, overcome the barriers of waste sorting at source in households. This study approached this topic by using two qualitative case studies. The first of the studies concentrated on the managers of the regional waste management and recycling companies, and the second one focused on consumers' views on the recycling of end-of-life textiles. The analysis showed that barriers for efficient recycling at households include both technical and motivational factors. As indicated by (Chu and Chiu, 2003), the barriers for recycling include resistance due to attitudes, the quality of the recycling services, and problems arising from culture. Our observations were related to the first two classes of this resistance, attitudes and services, as summarized in Figure 1. The technical barriers are related to the placement of the recycling services as well as the availability of the location and filling rate

information of the bins. IoT and AI technologies (Zhang *et al.*, 2019) that can provide enablers to overcome these problems are available (Esmaeilian *et al.*, 2018; Shukla and Hait, 2022), and it is possible to provide the consumers digital assistance to help them find the nearest recycling point and check its filling rates. However, the analysis shows that the part related to the consumers' attitudes and motivation to recycle plays a remarkable role in this. The empirical data showed that both waste management companies and consumers felt that technological solutions could be used to improve the households' activity to sort and recycle their waste in the correct manner. Smart processes enabled by digital technologies can enable a connection between the citizens and the provider of recycling services (Concari *et al.*, 2022), which in turn facilitate consumers' active participation in the design and development of the recycling services. The interview data also revealed that the data owned by waste management can enable the measurement of the waste recycling rate of households. It is possible to use this information in the rewarding of the households that exhibit high recycling performance, or use the recycling activity as the basis of waste management pricing. This all makes it possible to introduce incentive programs to promote good recycling behavior among households (Fontecha *et al.*, 2022). On the other hand, this kind of data-assisted motivation requires "continuous connectivity" between the service providers and the consumers (Rosemann *et al.*, 2021).

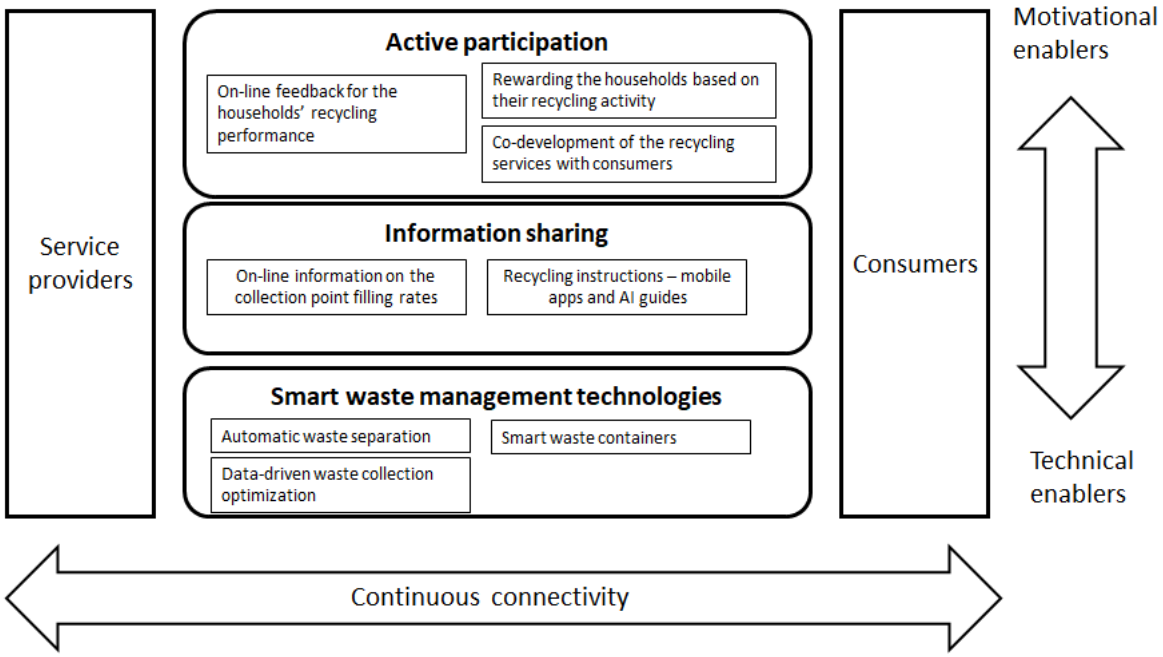

Figure 1 A summary of the findings related to the usage of the enabling technology in motivating consumers and households to recycle their waste.

CONCLUSIONS

In the spirit of the Industry 5.0 standard and smart cities (Rosemann *et al.*, 2021), it would be beneficial for waste management companies and the service developers in smart cities to involve consumers in developing. By utilizing continuous connectivity with the consumers, the providers of smart services can involve their end-customers in the development of the services and also share valuable information with them concerning recycling. Children should also be involved when developing services, as families engage children in households' waste separation (Saeedi *et al.*, 2023). The innovation activities of individual service users and their communities can also foster user entrepreneurship (Radu and Voda, 2022).The business sector actors can in this way understand how the user would implement a service or how they could be motivated to sort their waste recycling, e.g., via real-time information and gamification. Using the IoT-based measurements, waste management data and other digital enablers, the companies can create information for their

household customers on the benefits of their biowaste separation, for example, in the form of kilometers driven by a biogas bus in a year. Green thinking is a strong motivator for the consumers to sort their waste (Wang *et al.*, 2019), but evidence based on the waste data can also be a convincing motivator for them to make it a priority to recycle their waste correctly (Fontecha *et al.*, 2022).

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