



Research Paper

Japanese public perceptions on smart bin potential to support PAYT systems

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ABSTRACT

Smart bins can increase transparency and accuracy in monitoring waste characteristics such as weight, volume, and disposal times. This information can aid in enforcing waste reduction policies, including the pay-as-you-throw (PAYT) system. However, the public's response to this technology remains uncertain. Despite Japan's reputation for high waste separation compliance and collection rates, it has one of the world's highest per capita rates of plastic and packaging waste generation. This study surveyed 1000 Japanese individuals regarding their perception of smart bin features and their potential to encourage waste reductions. Multiple correspondence analysis (MCA) was used to explore the relationships between respondents' social attributes and their responses. The findings indicate a slightly higher responses from younger respondents (above 85 % of those age 10–29 compared to around 75 % of those aged 60 and older) who were in favour of smart bin technology functions such as unscheduled waste pick up and automatized waste separation. On the other hand, there was a strong unwillingness (0.57 count ratio) to reduce plastic waste even if a smart bin assisted PAYT is introduced from those who did not engage in waste separation and cleaning in the first place. Finally, an open-ended question about strategies to reduce plastic waste resulted in a large portion of mindset change ideas (24.8 % of the female respondents) and technology innovations proposals (24 % of male respondents). Although development of a smart-bin prototype is taking place, behavioral change strategies to foster a willingness to reduce waste must take place along with technological interventions.

1. Introduction

Waste reduction or avoidance is placed at the top of the waste management hierarchy; it is prioritized over reuse and recycling (European Commission, 2008; Ministry of Environment, 2005). Consequently, measuring waste is necessary not only to understand the reduction status but also to formulate achievable goals and effective reduction strategies. As the saying goes, “you cannot manage what you do not measure”, (Elgie et al., 2021) argues that accurate data is an important element for cities' transition towards more sustainable and circular waste management. The same study claimed that the current practice of measuring waste at the macro level by proxy is not good enough. For example, currently, material flow accounting is performed only by employing import and export data. At the micro level,

measuring waste is even more challenging; reduction at source has been estimated using available data such as from the amount of waste treated, disposed of, and recycled (Sakai et al., 2008; Skumatz, 2000).

Various strategies have been implemented to monitor household waste reduction at sources more accurately. These strategies are summarized in a review paper by (Zacho & Mosgaard, 2016), who categorized them into 1) self-weighing, monitoring, or reporting, 2) use of garbage collection data from the local government, 3) use of control and pilot groups to compare changes, 4) attitude and behavior survey, 5) point of sales data, and 6) the combination of the previously mentioned approaches. Some of these approaches are very laborious, resource intensive, and daunting and might not even be accurate. However, the recent accelerated growth of smart technologies has allowed reduced manual workload through sensors, data analytics, and automatization.

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(Esmailian et al., 2018) summarized studies about IoT-enabled waste management systems and categorized them into 1) development of data acquisition and sensor-based technologies, 2) development of communication technologies and data transmission infrastructure, 3) IoT systems capability experiments in the field, and 4) truck routing and scheduling for waste collection. Our previous study on the trend and readiness of smart waste management technologies (Shan et al., 2023) identified an increase in smart waste technology development projects worldwide. Specifically, while technologies such as monitoring dashboards for waste managers, contactless devices, and robotics for waste sorting peaked during the COVID-19 pandemic (Ogawa et al., 2023a; Onoda, 2020; Shan et al., 2023), the popularity of smart bins has steadily increased in the past decade and continues to increase today (Shan et al., 2023; Soni & Selvaradjou, 2018).

A “bin” in this study is defined as a container that is used to temporarily store household waste before the collection is transported to the final disposal site by the authority. On the other hand, “smart technologies” are considered technologies with a real-time ability to collect and analyse data that enable intelligent decision-making and automation (Thoben et al., 2017), using technology elements such as the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), and data analytics (Shah et al., 2022). Therefore, we define “a smart bin” as a temporary waste container that has a real-time ability to collect and analyse data supported by elements such as IoT, AI, ML, and data analytics to enable intelligent decision-making and automation.

A waste management system called the pay-as-you-throw principle (PAYT) is an adaptation result of the polluter pays principle introduced by the OECD in 1972, where those who produce more waste are charged more than those who produce less (OECD, 2022a). In this way, an economic incentive to reduce waste is created. However, this mechanism results in higher costs due to the need for waste weight/volume calculation to determine the charging fee and to establish the billing system (Alzamora & Barros, 2020). On the other hand, the prices of technologies usually decrease with higher readiness levels, improved efficiency, and mass production (Ihara et al., 2018). Therefore, we see an opportunity to support the PAYT mechanism by utilizing smart bins.

Previous studies that have supported the potential of smart waste technology to improve recycling practices have emphasized the importance of human behavior in conjunction with technical developments. For example, (Matiuk & Liobikiene, 2021), who performed a survey with 1027 Lithuanian respondents reported that ease of use of the technology should be prioritized to motivate people in engaging with recycling behaviors; (Steinhorst & Beyerl, 2021) who interviewed 28 experts from various sectors in Germany concluded that increasing environmental awareness and effective communication are key in plastic waste elimination strategies; (Yang et al., 2022) reported the difficulty of measuring the effects of an incentive-based recycling scheme on a larger scale since not all communities implement the same measure in Shanghai, China; In Europe, it was clear that higher digitalization has brought a positive impact on the mitigation of plastic waste (Khatami et al., 2023). Those studies have done great jobs in employing both large respondent-size quantitative and small respondent-size qualitative analyses on the topic. The cases were also taken in both the European and Asian countries. However, none focused on smart bin technology, and none covered Japan as a case study. Considering that Japan is one of the leading countries in technological innovation, with high (near 100 %) collection rates (World Bank, 2018), and has high public cooperation in waste separation (Ministry of the Environment, 2014), understanding the Japanese public perception of the potential of smart bins to assist PAYT implementation is a novel importance. Japan's remaining problem in waste management is its high per capita waste production, particularly for plastic and packaging waste (Lee, 2022). Since the smart bin is the most popular smart waste management technology being developed globally, both before and more intensively after the pandemic (Shan et al., 2023), the Japanese public perception, particularly of this technology, can provide a clear insight into

addressing the global issues on plastic waste.

In this study, the potential of smart bins' social acceptance in supporting PAYT system implementation is explored by asking 1000 Japanese people with equal age and location distribution, whether they would cooperate with such an idea. Both quantitative and qualitative questions were asked in this study and analysed with multiple correspondence analysis (MCA). MCA allows to deliver new insights based on a large set of data without a clear structure. This study use MCA in conjunction with Chi-Square and Cramer's V that amplifies the accuracy of significant relationship identification and strength of correlation between variables (Pandyaswargo et al., 2022, 2023).

2. Literature review

2.1. PAYT system: Advantages, disadvantages, and opportunities

Municipalities worldwide commonly apply flat charging systems instead of PAYT systems. The advantage of flat charging is that it does not require complicated calculations, so it is easy to understand and thus is popular. However, while the flat charging approach has been adequate to secure the funds needed to operate and maintain municipal waste management, the way everyone will pay the same amount regardless of how much waste they produce does not create any incentive for people to reduce their waste (Alzamora & Barros, 2020).

By employing a PAYT system, the cost of waste management can be adjusted to how much waste people produce. This approach will send a message to the people that waste management is not for free and fluctuates just the way other utilities, such as water and electricity consumption, are (Alzamora & Barros, 2020). The advantages of a PAYT system are that it provides 1) the mechanism to charge those who produce more waste than those who produce less (Alzamora & Barros, 2020; Barthakur, 2021) and 2) simple feedback that is powerful in improving people's behavior in their waste production (Ukkonen & Sahimaa, 2021).

On the other hand, there are also several disadvantages of PAYT. For example, 1) as there are various ways to calculate the charge in a PAYT system, the effectiveness of waste reduction may vary and may not give consistent results over time (Sakai et al., 2008); 2) how fair the calculation methods and the factors considered in the calculation method can be very subjective. For example, on how responsibilities should be distributed not only among the citizens as end-users but also among the manufacturing industries, distributors, and retailers of consumable products; and 3) there are also certain groups of people such as low-income people, large family sizes, elderly individuals, and the disabled, who, depending on how the PAYT charge is calculated, may be protected or disadvantaged by the system (Batllell & Hanf, 2008).

There are various ways to determine charges in the PAYT system. The most common method is calculating the amount of residual waste and then charging the people based on it. This approach will urge people to separate their waste for recycling or minimize their waste (Batllell & Hanf, 2008). However, it does not specifically encourage people to consume less packaging and recyclable waste. The other approach is using paid plastic bags and stickers that can be utilized for a more inclusive charging system where for example, free bags are distributed in limited amounts to lower-income families or adjusted to family sizes. However, the risk of this approach leading people to conduct illegal dumping is not zero (Batllell & Hanf, 2008; Sakai et al., 2008).

Currently, there are two approaches to how waste can be measured to determine the monthly charges: by weight or by volume. Weight measurements are usually taken by an equipped truck, whereas volume measurements and charging are performed through paid bags and stickers. Another way to measure volume is by the bin size (Alzamora & Barros, 2020). Finnish studies have suggested that while both weight- and volume-based approaches result in higher costs than flat charging systems, weight-based charging may be more effective in encouraging waste reduction than volume-based charging (Ukkonen & Sahimaa,

2021).

There is a potential to improve the fairness in charging and measurement precision by utilizing the smart bins' ability to detect the type of waste. While such an expected feature from future smart bins is still at a low readiness level, developments are taking place. For example, image-based sensors are particularly trained for industrial waste sorting technologies (Cheng et al., 2023; Koyanaka & Kobayashi, 2023). (Soni & Selvaradjou, 2018) conducted a comprehensive survey on the types of sensors applied to smart bins. For example, ultrasonic, load cell, proximity, gas equality, temperature, humidity, metal, methane, and odor sensors have been adopted in various smart bin development projects.

Despite the various experiments and developments, it is unknown which features of these sensors people would find helpful in encouraging a waste reduction. Therefore, there is a need to survey potential users about their perspectives on various smart bin functions. Understanding people's perspectives may help resource efficiency in developing a smart bin with higher social acceptance, more effective waste reduction strategies, and a fairer fee calculating system. Moreover, the survey process itself may build people's awareness and cooperation in future policy implementation. Studies have found that to be effective and fair, waste

management fee systems should take into account geographical differences, existing monitoring functionality, waste compositions (Ukkonen & Sahimaa, 2021), infrastructure, information feedback systems, transparent pricing policies (Bilitewski, 2008), and various service and income levels (Ukkonen & Sahimaa, 2021). It is, therefore, important to look at the issue in a specific geographical area. We take Japan as a specific focus of this study because the country is known for its technology innovation and demand for automation due to population aging (Park et al., 2022), high waste collection rate (World Bank, 2018), and citizen cooperation (Ministry of the Environment, 2014), while it still faces a high per capita plastic and packaging waste challenge (Lee, 2022).

2.2. PAYT system in Japan

Municipal waste in Japan is managed under the municipality administration. Although not all municipalities have adopted the PAYT system, many cities with a population under 30,000 have adopted it in various approaches (Fig. 1). The main reason why cities with larger populations have not adopted PAYT despite the same need to reduce

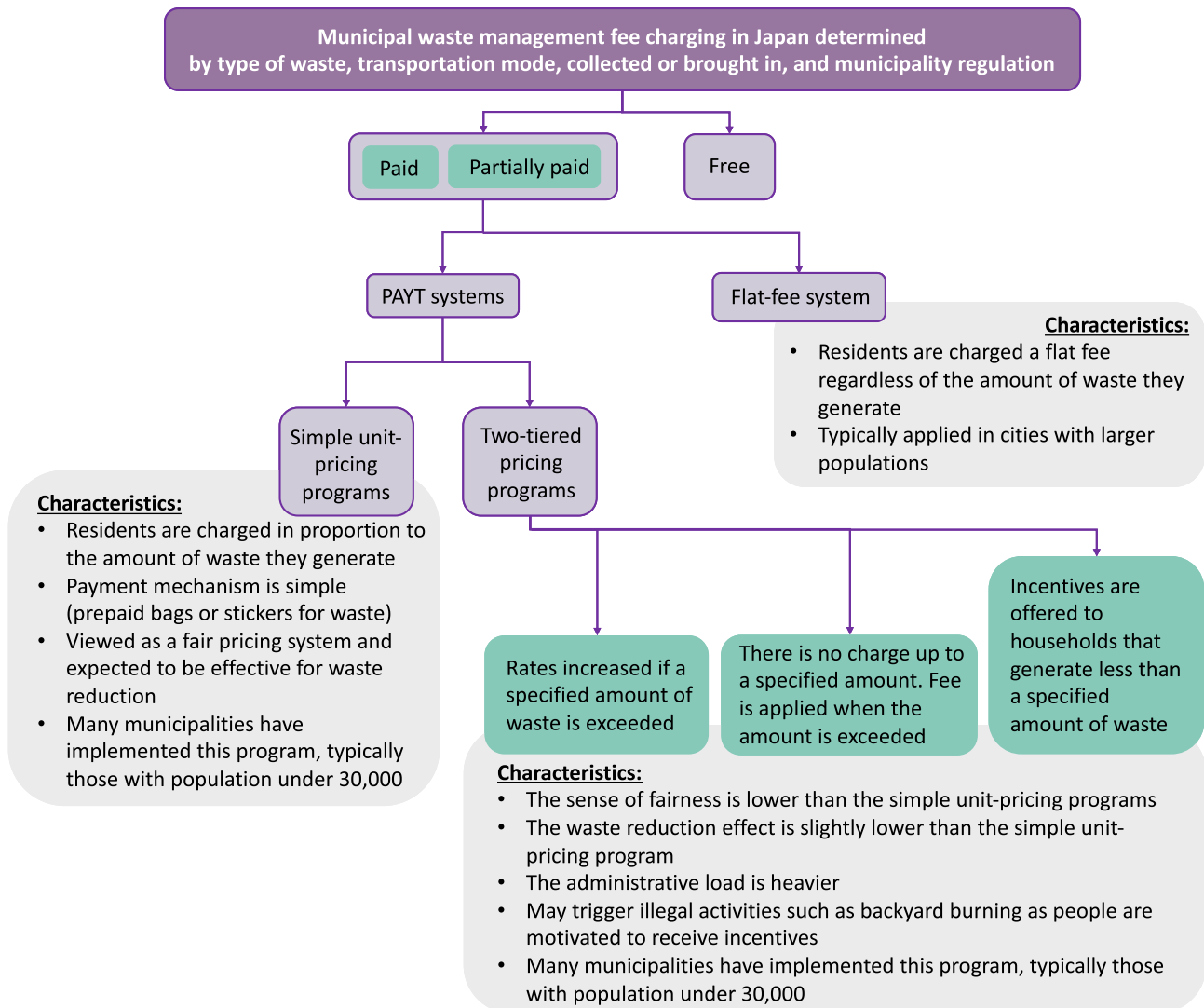


Fig. 1. Variance of PAYT charging system in Japan and their characteristics (summarized by author from (Sakai et al., 2008) and (Ministry of the Environment, Environmental Recycling and Resource Recycling Bureau, Waste Processing Promotion Division, 2023)) *A 45 L size trash bag is commonly used in Japanese municipalities along with other smaller sizes, such as the 20 L trash bag (Ogawa et al., 2023). ** Since the plastic waste is not sorted, it is not possible to calculate the conversion to a 45 L garbage bag. ***Actual questions: Japan is known among the highest per capita plastic waste producer in the world (Heinrich Boll Stiftung, 2021). Other than the charged plastic bags, what other ideas do you have that may help with plastic waste reduction in Japan?

waste is that it is difficult to gain consensus from the citizen (Sakai et al., 2008). The collection fees for municipal waste (including household and business waste) in Japan are determined by the type of waste, transportation, and whether it is collected or directly brought in by the waste producer. The collection fees are divided into three categories: 1) Paid, 2) Free, and 3) Partially charged. If paid or partially charged, the fee is classified into 1) PAYT, 2) fee-based, 3) flat rate, and 4) collected only if the amount is over a certain level (Ministry of the Environment, Environmental Recycling and Resource Recycling Bureau, Waste Processing Promotion Division, 2023).

Studies on PAYT systems in Japan have shown varying results. Earlier studies reported varying results regarding waste reduction, cost changes, and the prevalence of illegal dumping (Sakai et al., 2008). The results variances may depend on the way the charge is determined (Sakai et al., 2008) and by social and economic changes (Matsuda et al., 2018). However, the clear cause is the current lack of a direct way to measure and quantify waste reduction. This inability has prevented accurate measurement of the effectiveness of waste prevention activities in Japan (Yano & Sakai, 2016). Therefore, the direct measuring potential of a smart bin may become a game changer in waste management policy making. Furthermore, policymakers in the waste management sectors have been interested in the consequences of introducing the PAYT system on various social values and its impacts on various social groups (Batllellé & Hanf, 2008). Therefore, this study explored the relationships between various people's social attributes and their responses to potential features of a smart bin. Moreover, as Japan has been noted as the world's 2nd largest per capita producer after the US (UNEP, 2018), this study paid some focus to plastic waste. The official term used for plastic waste in Japan translates to “plastic and packaging waste”; therefore, this term will be used in the rest of this paper.

3. Materials and methods

3.1. Data collection

To obtain the perspectives of the Japanese people, we contracted Rakuten Insight to conduct an online survey using questionnaires that the authors prepared. Rakuten Insight collected and tabulated the responses to the survey between August 2 and 7, 2023.

We selected Rakuten Insight among other survey service companies because of its large number of Japanese panel members, which is 2.2 million among its 15.1 million global panel members as of July 2022 (Rakuten Insight, 2022). To ensure the quality of the sample panel, the company sent out a survey to the panellists using the same survey content of the Japanese national census and other offline random sampling surveys to compare the consistency of results (Nakamura et al., 2021). Rakuten Insights, on our behalf, sent the survey invitations to respondents randomly selected from the panel. To avoid bias in acquiring the samples, the invitation was sent out according to an equal distribution of 1) gender, 2) age, and 3) location in Japan (northern, central, and southern Japan). Approximately 16,000 individuals were contacted, and approximately 1300 responses were obtained, resulting in an 8.13 % response rate. After incomplete and incomprehensible responses were excluded, 1000 responses were obtained. The 1000 responses included an equal number of male and female respondents, with 500 individuals in each group. The age range of respondents spread across eight intervals, including 10 s, 20 s, 30 s, 40 s, 50 s, 60 s, 70 s, 80 s, more than 80 s. The distribution of respondents in each age interval was even, with 125 individuals in each age range. Locations of respondents on a Japan's map can be presented in [SI 1]. Table 1 presents the descriptive statistics of the remaining basic social attributes of the respondents. Fig. 2 summarizes respondents' responses to the following characteristics: 1) Weekly household plastic and packaging waste volume, 2) Whether they clean and separate their plastic and packaging waste, 3) Their perspective on the necessity of a technology that allows them to throw their garbage anytime (as opposed to the currently

Table 1

Summary of respondents' basic social attributes.

| Variable | Obs. | Percentage (%) |
|--|------|----------------|
| Household size | | |
| 1 Person | 233 | 13 |
| 2 Persons | 331 | 33 |
| 3 Persons | 206 | 21 |
| 4 Persons | 149 | 15 |
| 5 Persons | 56 | 6 |
| 6 Persons | 13 | 1 |
| 7 Persons | 7 | 1 |
| 8 Persons | 1 | 0 |
| 9 Persons and more | 4 | 0 |
| Occupation | | |
| Company employee (general employment) | 184 | 18.4 |
| Company employee (career track) | 44 | 4.4 |
| Company employee (executive) | 23 | 2.3 |
| Civil Servant/University Faculty/Non-Profit Organization | 49 | 4.9 |
| Temporary employees/contract employees | 33 | 3.3 |
| Self-employed | 37 | 3.7 |
| Agriculture/Forestry/Fisheries | 3 | 0.3 |
| Construction industry | 1 | 0.1 |
| Professional (Legal) | 3 | 0.3 |
| Professional (medical) | 40 | 4 |
| Professional (Education) | 2 | 0.2 |
| Part-time worker | 95 | 9.5 |
| Housewife | 118 | 11.8 |
| Student | 139 | 13.9 |
| Unemployed | 220 | 22 |
| Freelance | 3 | 0.3 |
| Retiree | 6 | 0.6 |
| Place of residence (asked down to the city name) | | |
| Northern Japan (Hokkaido) | 250 | 25 |
| Central Japan (Honshu and Shikoku) | 500 | 50 |
| Southern Japan (Kyushu and Okinawa) | 250 | 25 |

practiced time-scheduled collection), 4) Their perspective on the necessity of a technology to automate waste separation, 5) Their self-predicted behavior of reducing waste if a weight-based PAYT system is introduced, and 6) Ideas for waste reduction other than the already introduced paid single-use plastic bags.

3.2. Methodological framework

The methodological framework of this study is presented in Fig. 3. This study employs MCA and nonparametric tests, Chi-square (Eq. (1)) and Cramer's V (Eq. (2)) methods to analyse the collected data (Acock and Stavig, 1979). Where X^2 is Chi squared, O_i is observed value, E_i is expected value, V is Cramer's V coefficient, n is total number of observations, number of rows in the contingency table, and c is number of columns in the contingency table.

$$X^2 = \sum (O_i - E_i)^2 / E_i \quad (1)$$

$$V = \sqrt{X^2 / n \times \min[(r - 1), (c - 1)]} \quad (2)$$

And then, we measured the count/expected count ratio (eq.3) to test the direction of relationships between the observed and the expected data counts (positive relationship if more than 1, negative if less than 1).

$$\text{Count ratio} = O_i / E_i - 1 \quad (3)$$

The detailed procedures of the methodologies have been elaborated in (Pandyaswargo et al., 2022, 2023). The following strength points of MCA make it an ideal method for this study: 1) its ability to provide insights from a large set of data (IBM, 2021) and 2) its interpretation-

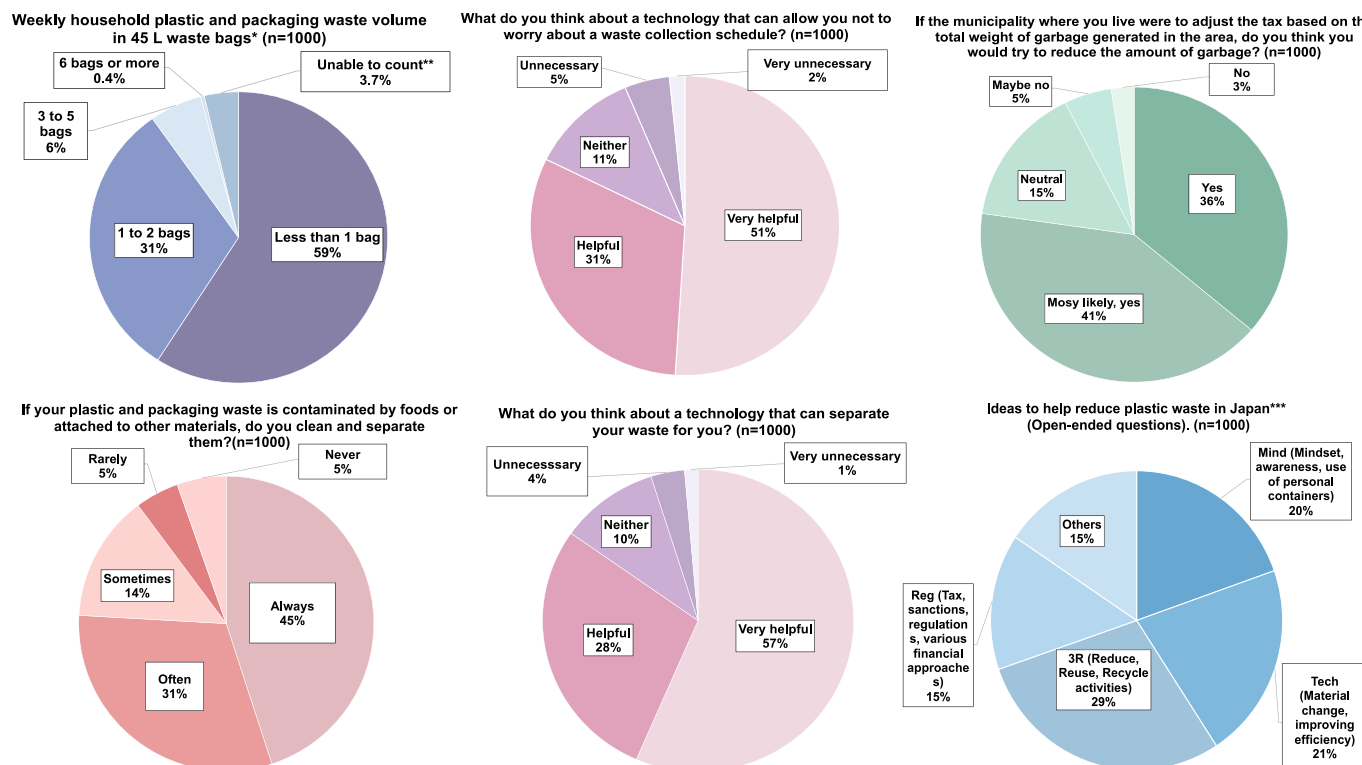


Fig. 2. Summary of respondents' responses on their household waste disposal.

friendliness. The first point is important for this study because the object of analysis (a smart bin) is a less-known subject due to its newness; therefore, an exploratory correlation analysis employing MCA could open the gate to finding meaningful insights. The second point helps to indicate the correlation between variables quickly. For example, by observing the MCA graphical output, the relationships among respondents' attributes and responses can be identified simply by identifying their distance proximity. Other aesthetic indicators, such as changes in colors, can also indicate the relationship's intensity. However, a few drawbacks of MCA are its inability to indicate either the significance and to provide a high accuracy of strengths of the identified relationships among variables. In this study, we address these drawbacks by performing nonparametric tests following an MCA: 1) the chi-square test to prove or disprove the significance and 2) the Cramer's V test to determine the strength of the identified significant relationships (IBM, 2024).

3.3. Multiple correspondence analysis preparation

Before performing MCA, the collected data are classified into several categories [SI 2] for easy and useful interpretation. Data categorization was guided by the frequency quartiles of the data, where applicable. The detailed walkthrough of the MCA employed in this study has been elaborated in (Pandyaswargo et al., 2023). The functions and packages employed are from the R programming language FactoMineR package. We follow the guidelines and principles of MCA from (Abdi & Valetin, 2007) and (Roux & Rouanet, 2010). Codes for the graphics were adapted from (Kassambara, 2017) and (Sanchez, 2013).

4. Results

4.1. Relationships identified by the MCA

The graphical output of MCA is shown in Fig. 4. The lighter areas indicate the higher intensity of the relationship between the attributes.

The black plots represent the sample population. Lighter areas can be observed around attributes A_Me (aged 30 to 59), O_Hi (Full-time workers), T_Hi (high need for untimed waste collection), and AS_Hi (high need for automated waste separation technology).

4.2. Significant relationships identified by the nonparametric tests

Chi-square and Cramer's V tests were performed to 1) test which respondent's attributes or variables are in relationships with the identified clusters, 2) determine the significance and strength of relationships, and 3) identify the direction of relationships. The identified variables and attributes of the significant relationships (as indicated by the value of Chi-square < 0.001) are summarized in Table 2.

There are five identified significantly correlated variables [SI 4]. The first is that there is a significant 25.6 % of respondents age 60 and older who were neutral about or think that a technology that can allow them to throw their garbage anytime without worrying about the schedule of waste pickups is unnecessary or very unnecessary. The values from the younger respondents are smaller at 12.8 % of the 10 to 29 age group, 9.6 % of the 30 to 49 age group, and 20 % of the 50 to 59 age group (Fig. 5).

The second identified significant finding is a similar tone to the first one, where 22 % of respondents in the oldest group (60 years and older) were neutral about or perceived an automated waste separation technology to be unnecessary or very unnecessary. The values from the younger respondents are smaller at 13.2 % of the 10 to 29 age group, 8.4 % of the 30 to 49 age group, and 11.2 % of the 50 to 59 age group (Fig. 5).

The third identified significant finding is from the open-ended question about ideas around strategies for plastic waste reduction. Although there are equal major suggestions related to reduce, reuse, recycle (3R) strategies implementation (32 % of female and 25.8 % of male respondents), other ideas by the male respondents were on technological solutions (24 % of them) both in the manufacturing end, such as redesigning plastic and packaging products with paper, biodegradable, or other innovative materials, and in the disposal end, such as

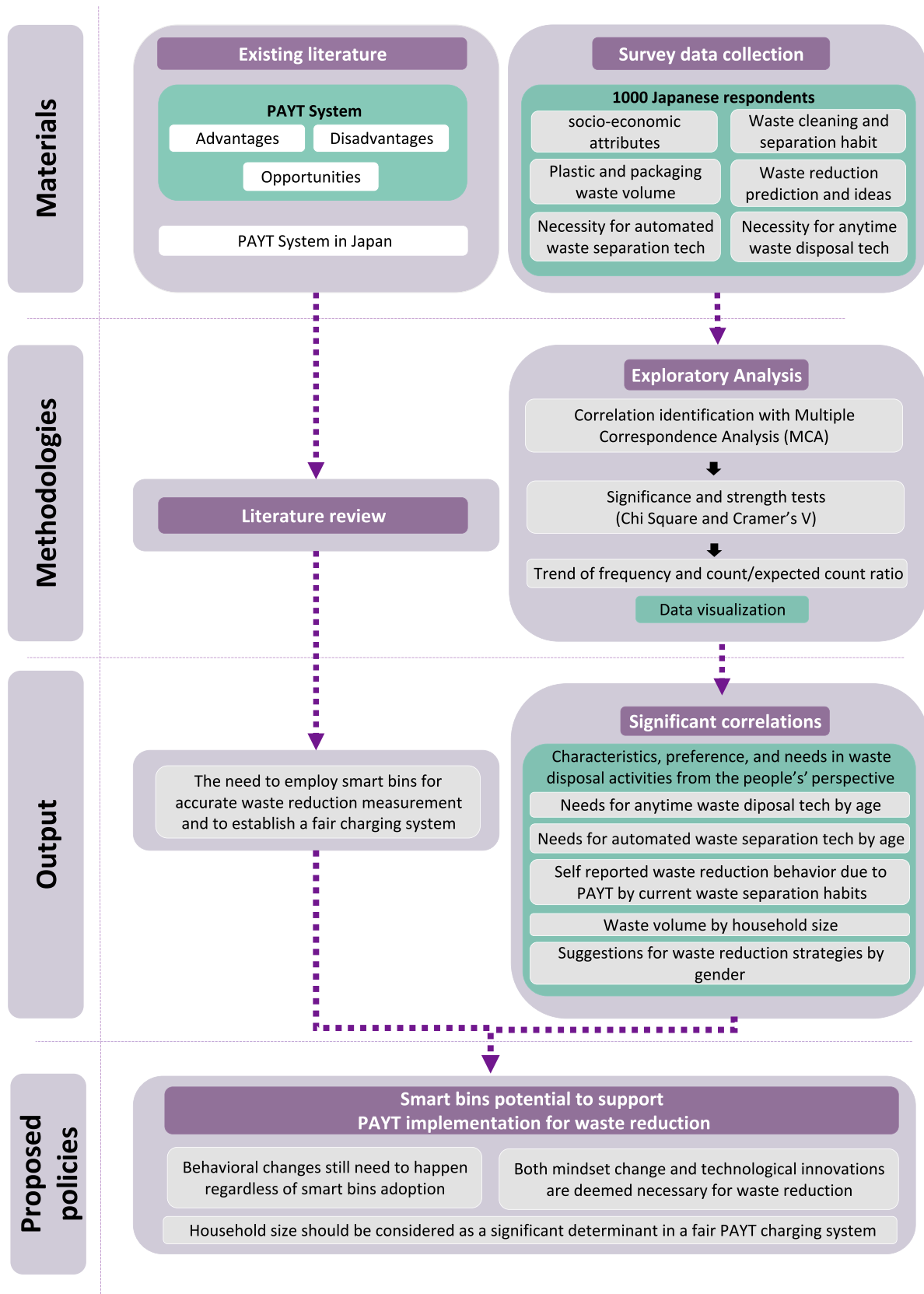


Fig. 3. Methodological framework. This study analyses the literature, collects data through a survey, and identifies the respondents' characteristics, preferences, and opinions on smart bin features for waste reduction.

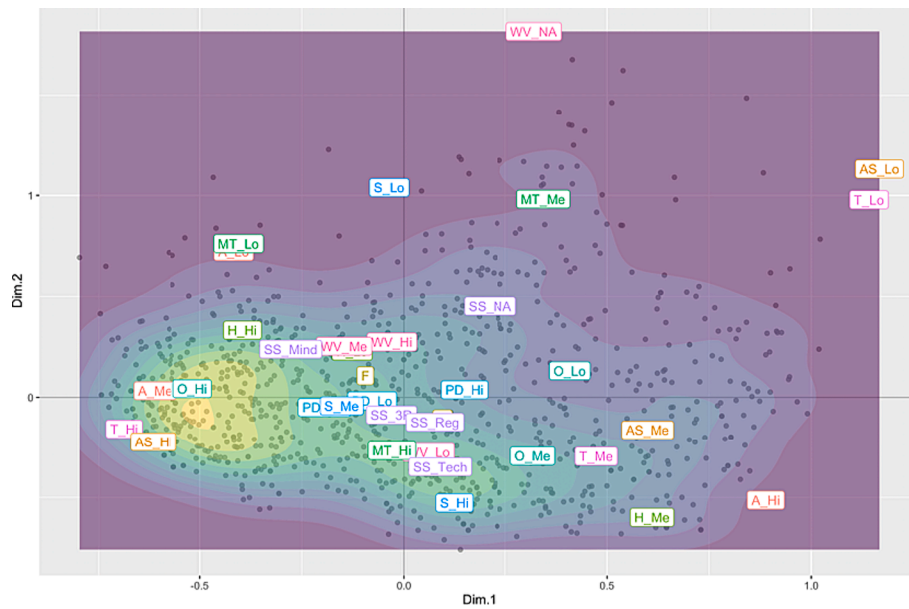


Fig. 4. MCA plotting output. A: Age, G: Gender, O: Occupation, H: Household size, PD: Population Density, WV: Waste Volume, S: Cleaning and Separating, T: No Time-scheduled Collection, AS: Automated Waste Separation, MT: PAYT-adjusted Municipality Tax, SS: Suggestion for Strategies to reduce plastic and packaging waste, Hi: High, Me: Medium, Lo: Low.

Table 2

Identified significant relationships based on Chi-square and Crammer's V.

| Cross table parameters with significant chi-square test p value | Test Results | | Largest count/expected count ratio | |
|---|--------------|-------------|--|----------------|
| | Chi-square | Crammer's V | (RowVariable_Category* ColVariable_Category: Count) | Expected Count |
| Age*No time-scheduled collection | <0.001 | 0.185 | A_Hi*T_Lo: 510 | 191.3 |
| Age*Automated waste separation | <0.001 | 0.150 | A_Hi*AS_Lo: 57 | 84 |
| Gender*Suggestion for reduction strategies | <0.001 | 0.161 | G_M*SS_Mind: 72 | 93.8 |
| Household size*Waste Volume | <0.001 | 0.179 | H_Hi*WV_Hi: 37 | 26.7 |
| Cleaning and Separating*PAYT adjusted municipality tax | <0.001 | 0.135 | S_Lo*MT_Med: 60 | 36.9 |

improving the efficiency of incineration and recycling facilities. On the other hand, a large proportion of the female respondents emphasized the importance of mindset change (24.8 %), such as using personal containers, not buying or using more than needed, and expanding the reach of environmental education.

The fourth identified significant finding is that larger households produce more waste than lower households (Fig. 5). Specifically, there is a significant 0.38 count ratio of households larger than 3 people with high level waste production (more than 3 bags a week). While this finding is obvious, it verifies the validity of the other findings in this study. Finally, the fifth identified significant finding is that there is a large portion of respondents (at 0.57 count ratio) who reported that they have not been cleaning and separating their plastic and packaging waste predicted that they might not reduce their plastic waste even if their municipality tax is adjusted with the amount of waste their community produces. Fig. 5 further exposes the findings where people who clean and separating their waste (sometimes or always), predict that they might reduce their waste, but only at a 0.08 count ratio.

5. Discussions

The results of this study have identified the significant correlations between Japanese respondents' socioeconomic attributes and their perceptions of the possible features that a smart bin can offer to facilitate PAYT and waste reduction. Although the Cramer's V for all of the findings identified in this study are of lower strength (lower than 0.2 (IBM, 2024)), they are significant (chi-square value < 0.001).

The most surprising result is that those who do not necessarily feel that technologies that could free people from worrying about time-scheduled waste pickups comes from the oldest group of people (at 25.6 % of people aged 60 and older). Furthermore, the same age group also expressed a higher feeling of unnecessary (at 22 %) towards automatized waste separation technology compared to those aged 59 and younger. This is surprising because older adults are often associated with lower cognitive functions (Harada et al., 2013), in this case, to remember waste pickup schedules or to separate their waste. Although the association might be physiologically correct, the finding in this study shows that the older group does not necessarily prefer technology to replace their responsibility to separate and cooperate with the waste disposal schedule. Conversely, most of the younger respondents show strong positive reactions (87.2 % and 86.8 % of the 10 to 29 years old are in favour for untimed collection and automatic separation technology, respectively) towards the suggested features of smart bin technology. While such results may be influenced by how long the older group of people have gotten used to separating and disposing of their waste on schedules, presently, almost a third of the Japanese population is 65 and older (The World Bank, 2022). The fact that there is a large older population that continues to grow at speed (OECD, 2022b) implies that the opinions of older adults cannot be simply ignored, no matter how unpopular they may be.

The other notable finding in this study is the strong expression of unwillingness (0.57 count ratio) to reduce waste even if the municipality tax is PAYT adjusted from the group of people who reported not separating and cleaning their plastic and packaging waste before disposal. As

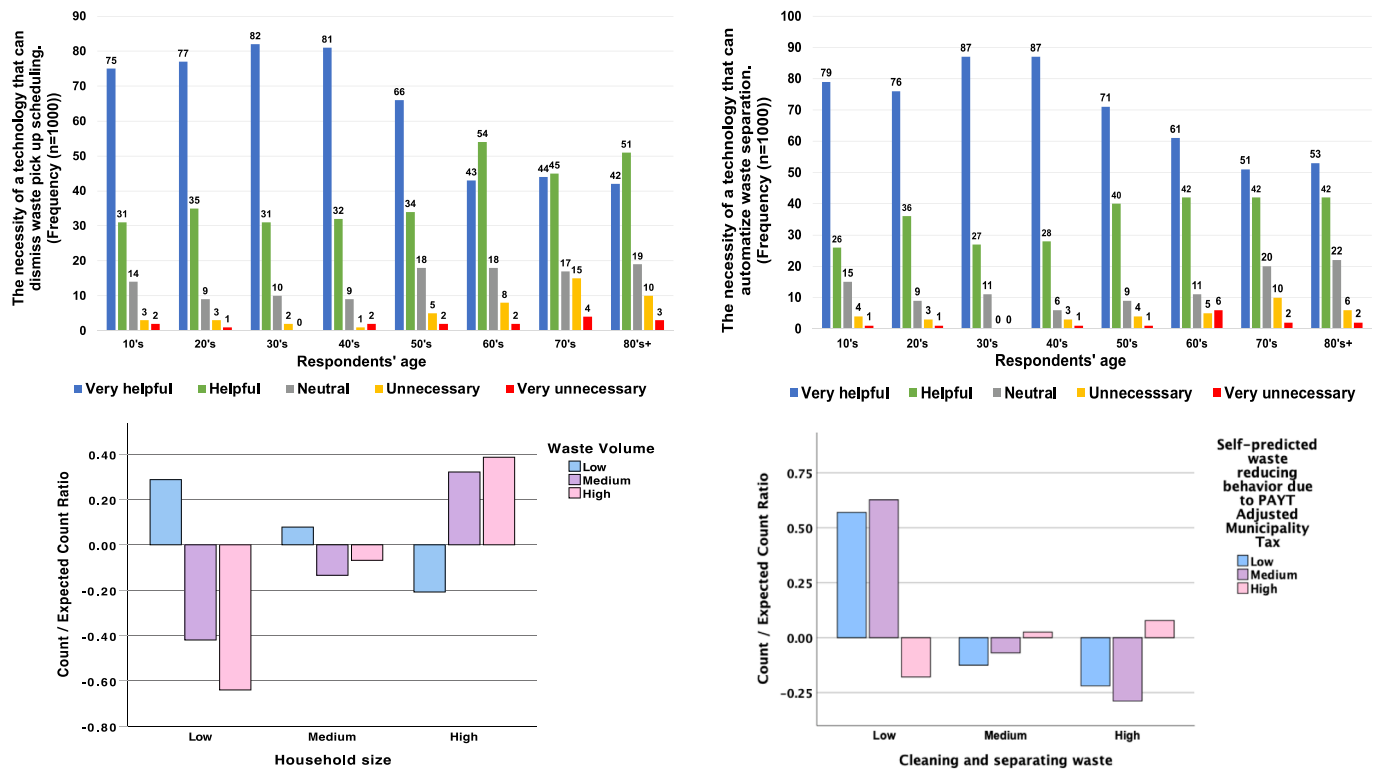


Fig. 5. Response frequency and ratio distribution by age and household size.

the opposite end is also true (those who separate and clean might reduce their waste), it can be concluded that waste reduction might not be solely influenced by financial incentives (or disincentives). The other significant finding from this study shows a possible factor: mindset rather than technology that was suggested by the female respondents. The high response (24.8 %) about mindset to reduce waste among the female respondents might be influenced by their main role in Japanese households, as household managers and main child caregiver (Iijima & Yokoyama, 2018). The mindset argument is also in line with a study by (Kawasaki et al., 2022) that explored the significance of childhood education and religious values' long-lasting influences on avoiding food wastage. Other strong cultural traits of the Japanese waste disposal habit have been reported by (Ichinose et al., 2015; Yamamoto & Eva, 2022), where decision-making in Japan is known to be heavily influenced by one's neighbors. The question about self-predicted waste-reducing behavior in this study tested this theory because the PAYT-adjusted tax was suggested based on the weight of collective waste from a neighborhood. Based on the findings in this study, where some people do not think they would reduce their waste that way, perhaps the neighbor influence value only applies to those who are already in compliance with waste separating, cleaning, and other waste disposal regulations in the first place.

There was no significant correlation found between the density of the respondents' city of residence and any of their responses. This may imply that the current PAYT system, which is typically already implemented in cities with lower populations (Sakai et al., 2008), does not influence how respondents answer the questions asked in this study.

Because the income gap in Japan has been relatively low at the Gini coefficient of around 0.3 for an extended period (OECD, 2023), we do not include the income question in the study. Furthermore, the slight increase in the Gini coefficient in the last couple of decades is mainly caused by increased poverty. The dramatic increase in the aging population and single-person households are the cause this poverty (OECD, 2012). This study has taken care of the age variable by ensuring that each age group is represented equally. Furthermore, we also extensively

discussed the results based on household size.

Regarding Japan's national agendas, the country has a similar priority hierarchy regarding waste management to the European Union's waste management pyramid. The first approach in waste management should be to suppress waste generation, followed by recycling and then recovery. It also emphasizes that landfilling should not be an option (Ministry of Environment, 2005). In particular, plastic waste is classified as a priority area 1 for greenhouse gas (GHG) emission reduction from waste, where reducing and reusing actions should be maximized before recycling and substituting biobased recycling (Yamada et al., 2023). Furthermore, following the China plastic waste import ban, Japan has issued several ambitious targets, such as 60 % recycling and reuse for containers and packaging waste by 2030 and aiming for 100 % utilization of used plastics by 2035 and a 25 % reduction in plastic waste by 2030 (Japanese Ministry of the Environment, 2019).

Because there is an equal amount of plastic waste produced by households and the manufacturing industry, reducing waste from the industry is equally important. Acts and regulations such as the "Fundamental Law for Establishing a Sound Material-Cycle Society" and The "Resource Circulation Strategy for Plastics" have resulted in waste reduction through technological innovations from the industry, such as lighter weight PET bottles, and regulatory introductions, such as nationwide charged plastic bags with positive results (Yamamoto & Eva, 2022). In this sense, the significant male respondents' responses (accounting for 56.6 %) found in this study where technological intervention is important are also correct. This view is also supported by (Brunel, 2019), who found that historically, the decline of Japan's plastic waste needed significant innovation efforts.

6. Smart-bin prototype for contactless waste collection and transportation in Japan and the world

The COVID-19 pandemic has called for a shift to non-contact garbage collection in Japan. Efforts are being made to automate garbage collection using overseas-made smart bins with advanced functions,

such as compression and sensors that can detect the amount of garbage, and mobility devices with automatic driving functions (Smago, 2023). Despite the identified needs for such technologies, only several domestic initiatives respond to the demands (Onoda, 2020). An example of the initiative is by the Environmental Intelligence Innovation company (EII Co., Ltd.), which has developed an AI automatic vehicle dispatch system specialized for the industrial waste collection and transportation industry (Hu, 2022). The study reported difficulty sustaining the technology due to a lack of human resources in the industrial waste collection and transportation industry. To this end, the company has built a software as a service (SaaS) system called “Waste Force” that integrates a core business system and an automatic dispatch system (Hu, 2022). In the field of medical waste, a system that utilizes IoT to support proper treatment of hazardous waste and improve the efficiency small-lot collection is being developed. In medical waste, a system that utilizes IoT to support the proper treatment of hazardous waste and improve the efficiency of small-lot collection is being developed. Our laboratory is developing an on-demand and traceable system collection system based on interviews and surveys with small-scale medical institutions (Yoshidome et al., 2022).

While there have been several technological developments using AI and IoT in industrial waste collection, research focusing on smart waste collection for municipal waste is quite limited in Japan. Therefore, this study tackles the social issues that must be resolved to approach the automation technologies intervention for municipal waste collection in Japan.

On the technical side, we are currently developing prototypes of a smart bin and a mobility device for non-contact municipal waste collection. We have performed a proof of concept (PoC) study in the Minami-Kurihashi train station area in Saitama, Japan, to test the prototypes (Ogawa et al., 2023b). The prototype is not ready for societal implementation at the current improvement stage. Further improvements and demonstrations, such as compatibility improvements for various public road infrastructures and simultaneous operation of multiple mobility devices, will be made in future studies.

The technical specifications of the prototype bin are shown in the [supplementary material](#) [SI 3]. Fig. 6 shows how the manually picked waste bags from the side of the roads can be replaced with a smart bin. Through sensors, the smart bin can detect the volume of waste that has been stored in it, and when it is full, it sends a signal through the IoT to order the mobility device to pick up the container, carry it, and dump it into the packer truck – all in a contactless manner. Our previous studies have reported the demonstration performance of the contactless waste collection prototype (Ogawa et al., 2023a). It was concluded that compared to the current manual practice, the developed technology operated with less labor. Furthermore, the required human contact is

significantly reduced. These advantages respond to Japan’s challenge of securing physical labor and the increased demand for labor safety and hygiene post-pandemic.

Outside Japan, the development of smart bins is also taking place at various stages of readiness levels. Our previous study analyzed a hundred smart waste management technologies and found smart bins with high readiness levels in China, Denmark, and France and lower readiness levels in emerging countries such as India, Thailand, and Indonesia (Shan et al., 2023). In the study, we discovered that although there is a high demand for technology in emerging countries, more work is required to integrate technology into the existing infrastructure. Other than advancing the prototypes technically, building the associated monitoring system, regulations, and the public society’s habits and cooperation with the technology would be equally important requirements for implementing the technology in society.

7. Conclusion

An accurate waste measurement at-source is required for an effective waste reduction. On the other hand, the waste disposal charge calculation can be supported by smart bins. In this study, we employed a questionnaire-based approach to collect and analyse the Japanese public opinion on the features of smart bins that may encourage waste reduction. We selected Japan due to its high per capita waste production despite its plausible achievements in the municipal waste collection rate and citizens’ cooperation in waste separation. From the questionnaire, we acquired information about respondents’ social attributes, their waste-separating habits, produced plastic and packaging waste volume, and their responses on the necessity of various smart bins and possible features that can help to reduce people’s burden in separating waste and observing waste pick up schedules. The questionnaire also captured respondents’ self-predicted behavior if PAYT was implemented and their further ideas for waste reduction strategies.

Utilizing the MCA method, we identified attributes linked to respondents’ characteristics. More than 85 % of the younger group (10 to 29 years old) of respondents showed a preference for untimed garbage collection and a desire for automated separation. On the other hand, there are slightly fewer (77.6%) respondents from the older group (60 and older) who expressed the necessity of those technology-assisted possibilities. Although overall, the majority of respondents from all age group are still in favour of the technologies. Regarding self-predicted waste-reducing behavior, those who do not clean and separate waste predicted that they would not reduce their waste even if a smart bin-assisted PAYT was introduced, at a large positive 0.57 count ratio. Conversely, respondents who have been cleaning and separating their waste predicted that they may slightly reduce their waste, at a low

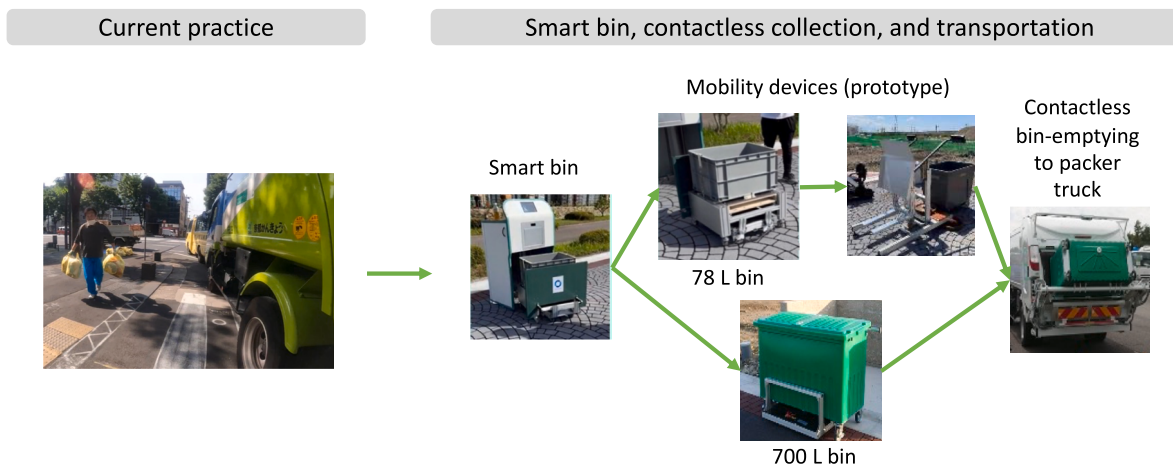


Fig. 6. The smart bin prototype for contactless waste collecting and transportation in Japan.

positive 0.08 count ratio.

These results imply that activities to promote waste reduction would still be necessary regardless of smart bin-enabled PAYT intervention. Regarding ideas for waste reduction strategies from the open-ended question, both the male and female respondents showed the majority of suggestions on 3R strategies (26 % and 32 %, respectively). Other responses from the male respondents were made up of 24 % technological ideas such as innovative alternative materials to replace plastics and efficiency improvement in manufacturing and disposal facilities, and regulatory solutions at 16.6 %. On the other hand, 24.8 % of the female respondents emphasized the importance of mind change, and education reflected in daily behaviors such as using reusable personal containers and not buying or using goods excessively, and regulatory solutions at 12.8 %. Finally, waste quantities correlate positively with household size. As there is a growing population of older adults living alone in Japan and the country's needs for population growth, a fair PAYT system should carefully consider household size.

On the other hand, our pilot project of the smart bin and contactless waste collection and transportation in Japan showed some technical success, including a reduced number of the required human labor and contact. Future studies should improve the integration of the developed prototypes in the actual environment and link the two spheres of research; the social acceptance aspects and the technological development sides, to create effective field-implementation strategies of smart bins.

CRedit authorship contribution statement

Chaoxia Shan: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation. **Andante Hadi Pandyaswargo:** Conceptualization, Data curation, Formal analysis, Validation, Visualization, Funding acquisition, Methodology, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing, Project administration, Supervision. **Akihisa Ogawa:** Visualization, Investigation, Data curation. **Ryota Tsubouchi:** Investigation. **Hiroshi Onoda:** Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hiroshi Onoda reports financial support was provided by Environmental Restoration and Conservation Agency. Andante Hadi Pandyaswargo reports was provided by Japan Society for the Promotion of Science. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.wasman.2024.02.003>.

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