Research on the implementation of household garbage classification from the perspective of big data analysis

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***Abstract*—In modern society, creating a harmonious and civilized environment has led to a significant emphasis on waste sorting policies and related industrial development. Big data technology has been widely applied in this area, benefiting social economy and construction. However, since adopting big data in China began relatively late, the relevant theories, especially in waste sorting, have not yet been fully developed. Therefore, it is necessary to improve waste sorting and management gradually by integrating big data technology. This study first outlines the basic concepts of big data and waste sorting. It defines the role of big data in developing the waste sorting industry based on policy implementation in a specific region. The research explores a big data-driven urban waste disposal system and the architecture of a waste sorting and recycling system using the Internet of Things. To assess effectiveness, residents from green demonstration communities and non-demonstration communities were selected as samples for comparison. Ultimately, the goal is to utilize digital technology better to advance waste sorting in China.**

Keywords—Big data, Smart sorting device, Waste sorting, Policy implementation, Industrial development

I. INTRODUCTION

During the 14th Five-Year Plan period, China entered a new phase in developing ecological civilization, actively promoting the synergy between pollution reduction and carbon reduction and fostering a green transformation in socio-economic development to improve environmental quality. Since 2008, big data technology has been widely applied across the globe. Although academia has yet to establish a unified definition, scholars have identified certain characteristics of big data, such as low-value density, high processing speed, and large data volume, which contribute to the formation of data resource libraries when related data is categorized and organized (S. Zhang et al., 2024). Waste sorting refers to a series of activities in which waste is stored, transported, and disposed of according to specific standards. (Tan et al., 2024). In China's waste sorting policy, household waste is divided into four categories: hazardous waste, kitchen waste, recyclable waste, and other waste. Due to varying local living habits, the composition of waste differs, leading to the principle of localized adaptation in addressing waste sorting issues. (Li et al., 2024).

Many cities in China have achieved excellent results in exploring the application of big data in waste sorting. Notable examples include first-tier cities such as Beijing, Shanghai, Shenzhen, and Jiangsu, where the use of big data technology to manage household waste sorting has become quite mature, and more cities are continuously exploring these practices (Chen, 2015; Huang et al., 2022). For instance, Nanning, as one of the second batch of pilot cities for implementing digital city management, has undergone several smart upgrades and transformations since its digital city management information system was established in 2007. In 2020, Nanning established a city-level comprehensive urban management service platform based on its original system, achieving connectivity with the national platform. This platform, through integrating and applying big data, cloud computing, and internet technologies, has created opportunities for big data governance in waste sorting, effectively advancing the modernization of Nanning's urban governance system and governance capacity.

The construction and application of Nanning's digital city management information system not only integrated and shared urban management resources but also enhanced the digitalization, refinement, and intelligence of comprehensive urban management services, increasing citizen interaction and significantly improving the city's civilized image. This development has also provided strong support for implementing Nanning's waste sorting policy, promoting the coordinated development of waste sorting and urban management. This paper first introduces the operating principles of an automatic recyclable waste sorting system in green demonstration communities. Then, through questionnaire surveys and data analysis, it collects data on residents' attitudes, behavioral intentions, and actual behaviors regarding waste sorting to assess the impact of big data technology on implementing waste sorting policies. Additionally, this paper compares the waste sorting behaviors of residents in green demonstration communities with those in ordinary communities in Nanning, exploring the impact of the big data-based system on residents' behaviors and the feasibility of using big data technology to promote the development of the waste sorting industry and the smart transformation of urban governance.

II. LITERATURE REVIEW AND HYPOTHESES

Recent years have seen the rapid development of the Internet of Things (IoT) and big data technology (Gubbi et al., 2013), leading to increasing attention to the application of smart sorting devices in waste sorting. Smart sorting devices, equipped with sensors, image recognition technology, and big data analysis capabilities, can effectively identify and sort different types of waste, automating and streamlining the waste disposal process. Studies have shown that these devices not only improve the accuracy and efficiency of waste sorting but also enhance residents' participation in waste sorting through a points reward system (Mortos et al., 2024). For example, L.-P. Zhang & Zhu (2020) found that using smart waste sorting devices significantly increased residents' sorting behaviors and raised their environmental awareness and sense of responsibility through an instant feedback mechanism. Furthermore, the widespread use of smart sorting devices has modernized community waste management, making urban waste sorting systems more intelligent and efficient. These devices also enable data collection and analysis, helping city managers better understand residents' sorting behavior patterns, thereby optimizing waste sorting policies and resource allocation.

The Theory of Planned Behavior (TPB), proposed by Ajzen in 1991, is a widely applied social psychology theory for predicting and explaining individual behavior. The theory posits that an individual's behavioral intention is determined by three key factors: attitude, subjective norms, and perceived behavioral control. These factors jointly influence an individual's behavioral intention, ultimately predicting their actual behavior (Ajzen, 1985). The introduction of smart waste sorting devices has the potential to influence key behavioral variables by providing residents with immediate feedback and rewards for their sorting efforts. This reinforcement mechanism can positively impact their attitude towards waste sorting, as consistently positive feedback is known to strengthen favorable evaluations of a behavior (Phang & Ilham, 2023; Sarpong & Amankwaa, 2022). This effect may extend to other categories of waste as well, as the reinforced behavior becomes more habitual (Lehr et al., 2020). Furthermore, the widespread adoption of smart devices within a community may contribute to the establishment of a social norm. According to social influence theory, when a behavior is commonly practised and visible within a group, individuals are more likely to conform due to perceived social pressure (Kwon et al., 2021). This increased conformity could encourage consistent sorting behavior across various waste categories. Lastly, by simplifying the sorting process, these devices can enhance residents' perceived behavioral control. The ease of use and efficiency provided by smart devices may reduce the effort required for sorting, which is crucial in increasing individuals' confidence in their ability to perform the behavior consistently (Malarvizhi et al., 2023). This enhanced perceived control could lead to a higher likelihood of sorting waste across all categories.

Additionally, the spillover effect is an important concept in behavioral research, referring to the impact that performing one behavior can have on other related behaviors. Wang et al. (2022) suggested that positive behavioral feedback can encourage individuals to exhibit more positive behaviors in other areas. For example, when individuals successfully sort waste with the help of smart devices, this positive experience may increase their willingness and ability to engage in other environmental behaviors. Particularly in the context of waste sorting, the experience of successfully sorting waste can lead residents to demonstrate stronger sorting intentions in categories not covered by the smart devices, thus enhancing overall environmental behavior. Could this spillover effect be particularly evident in the use of smart waste sorting devices, where the immediate feedback and positive reinforcement might extend beyond specific waste categories to influence residents' other environmental behaviors?

Based on the above, this study proposes the following hypotheses:

Hypothesis 1: Introducing smart waste sorting devices will significantly improve residents' attitudes towards waste sorting and enhance their behavioral intentions to sort waste.

Hypothesis 2: The use of smart waste sorting devices will generate a spillover effect, increasing residents' willingness and actual behavior in sorting waste categories not covered by the devices.

Hypothesis 3: Supported by smart waste sorting devices and a digital management platform, residents in green demonstration communities will perform significantly better in waste sorting behaviors than those in ordinary communities.

III. METHODS

A. *Waste Sorting and Recycling System*

In 2022, smart waste sorting devices were introduced in the Sheng Tian Ming Cheng Green Demonstration Community (Shèng Tiān Míng Chéng Lǜsè Shìfàn Shèqū) in Nanning. The first phase of implementation included the installation of bins for plastic bottles, paper, and used clothing, strategically placed next to the recycling house provided by Jingling Company (Jīnglíng Gōngsī). The recycling house is conveniently located beside the express delivery station, making it easier for residents to recycle packaging materials such as cardboard on the spot.

The smart recycling system is designed with multiple specialized bins, each dedicated to a specific type of recyclable material, including plastic bottles and containers, paper products, metals, glass bottles, small electronics, textiles, and medicine packaging. When a user deposits an item into the smart recycling machine, the system's advanced image recognition technology scans and categorizes the item. Utilizing machine learning algorithms, the system accurately identifies the item and matches it with the appropriate bin. If the item meets the sorting criteria, it is automatically sorted into the correct bin, and the user is rewarded through various methods such as mobile top-ups or digital credits. Additionally, the system provides real-time feedback through a display or audio prompts, ensuring proper user engagement. The collected data is analyzed to continually improve the accuracy of the recognition algorithm, enhancing the overall efficiency of the recycling process. This smart design not only maximizes resource utilization but also incentivizes users to actively participate in recycling activities, thereby contributing to sustainable waste management.

System operation begins with training machine learning algorithms using a dataset of waste images with various labels. This process builds and refines a waste sorting algorithm, which is then continuously improved through iterative training to enhance recognition accuracy. Figure 1 illustrates the system architecture.

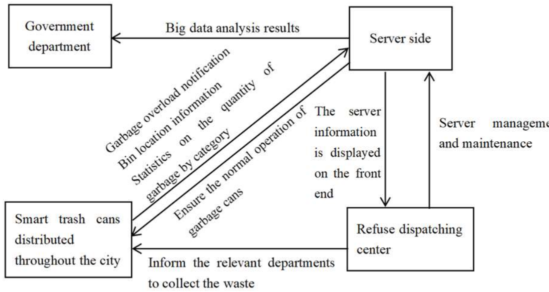

FIGURE I. SYSTEM ARCHITECTURE DIAGRAM

TABLE I. TABLE TYPE STYLES

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	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

To ensure accurate waste identification even in low-light conditions, such as at night or during rainy weather, each trash can is equipped with a small camera and an LED light. This setup allows the system to maintain high recognition performance regardless of environmental factors. The specific implementation framework is depicted in Figure 2.

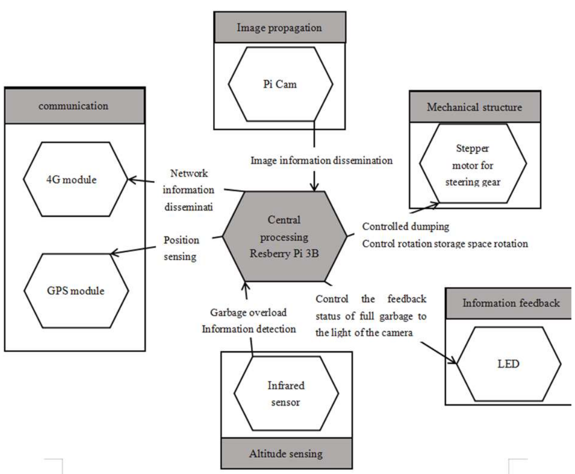

FIGURE II. PRODUCT REALIZATION FRAME DIAGRAM

B. HARDWARE DESIGN.

The hardware design is crucial for the system's functionality and efficiency. It includes a large-screen display system integrated with waste management and QR code modules. Once data is transmitted to the platform, the digital large screen or terminal provides a real-time interface for data visualization and analysis.

When users wish to dispose of waste, they interact with the large screen to either swipe a card or select the waste category. The system then prints a QR code at the bottom of the screen, which users attach to their waste bags for identification. This process is detailed in Figure 3.

Large screen display system		
Reservation management module	Garbage name and classification management module	Garbage management module
Information management module		Advertising module
Two-dimensional code module		Swipe card module

FIGURE 3. STRUCTURE OF THE SYSTEM ON A LARGE SCREEN

APP system		
Information upload module Personal information management module Two-dimensional code module	Garbage name and classification management module	Two-dimensional code module Garbage management module Financial management module

FIGURE 4. APPLICATION SERVER MODULE STRUCTURE

The design of the application server module is shown in Figure 4. Smart waste bins are designed to effectively collect and identify domestic waste. They include features such as intelligent alerts for incorrect waste placement and gradual improvement in sorting accuracy through machine learning. The overall system includes multiple modules shown in Figure 5.

Intelligent garbage bin system		
Acquisition and identification module	Access control module	Information upload module
Wireless monitoring and management module	Garbage can full No warning module	System self-check module

FIGURE 5. STRUCTURE OF THE SMART WASTE BIN

C. MEASUREMENT OF TPB VARIABLES

To measure the constructs based on the Theory of Planned Behavior (TPB), this study adopted scales from Xu, Ling, Lu, and Shen (2017). The TPB framework was utilized to assess residents' attitudes, subjective norms, perceived behavioral control, intention to recycle, and actual separating behavior. Specifically, three items were selected to measure intention to recycle, three items for separating behavior, four items for attitude, five items for subjective norms, and eight items for perceived behavioral control. The reliability of these scales, as indicated by Cronbach's alpha coefficients, was 0.887 for intention, 0.846 for behavior, 0.918 for attitude, 0.938 for subjective norms, and 0.940 for perceived behavioral control, demonstrating a high level of internal consistency for the constructs. For example, items measuring attitude included statements like "Waste separation helps to protect the environment and conserve resources; we should do it," and those measuring perceived behavioral control included questions like "Do you have enough time to carry out waste separation?" To verify the spillover effect, we not only measured residents' behavioral intentions and actions for recyclable waste but also assessed their intentions and behaviors regarding kitchen waste and hazardous waste.

This study employed one-way ANOVA to examine the differences between residents of green demonstration communities and ordinary communities on the Theory of Planned Behavior (TPB) variables, including intention (IN), behavior (BE), attitude (AT), subjective norms (SN), and perceived behavioral control (PBC). The means (M) and standard deviations (SD) for each group were calculated, and the ANOVA was used to test the statistical significance of differences between the two types of communities. All analyses were conducted with a significance level set at $p < 0.001$.

As shown in Table 1, the one-way ANOVA results reveal significant differences between residents of green demonstration communities and those of ordinary communities across all TPB variables. Specifically, residents of green communities reported significantly higher scores in intention, behavior, attitude, subjective norms, and perceived behavioral control than residents of ordinary communities.

For intention (IN), the mean score for green community residents was 4.071 (SD = 0.802) compared to 3.767 (SD = 0.857) for ordinary community residents, with an F-value of 13.604 ($p < 0.001$). Similarly, behavior (BE) scores were higher in green communities (M = 3.592, SD = 0.968) than in ordinary communities (M = 3.212, SD = 1.001), with an F-value of 15.04 ($p < 0.001$). Attitude (AT) also showed a significant difference, with green community residents scoring 4.392 (SD = 0.738) compared to 4.013 (SD = 0.767) in ordinary communities, yielding an F-value of 25.580 ($p < 0.001$). Subjective norms (SN) had a mean score of 4.133 (SD = 0.754) in green communities, higher than the 3.629 (SD = 0.682) reported in ordinary communities, with an F-value of 34.573 ($p < 0.001$). Lastly, perceived behavioral control (PBC) was also significantly higher in green communities (M = 4.030, SD = 0.731) compared to ordinary communities (M = 3.548, SD = 0.628), with an F-value of 35.684 ($p < 0.001$).

These results support Hypothesis 1, confirming that introducing smart waste sorting devices significantly improves residents' attitudes towards waste sorting and enhances their behavioral intentions to sort waste. Furthermore, although the devices primarily target recyclable waste, the higher scores in overall sorting behavior in green communities support Hypothesis 2, indicating a spillover effect that increases residents' willingness and actual behavior in sorting other categories of waste, such as kitchen and hazardous waste. Finally, the significantly better performance in all TPB variables by residents of green demonstration communities compared to ordinary communities validates Hypothesis 3, demonstrating that, supported by smart waste sorting devices and a digital management platform, residents in green demonstration communities perform significantly better in waste sorting behaviours.

TABLE. 1. ONE-WAY ANOVA RESULTS FOR TYPES OF COMMUNITY ON THE TABLE VARIABLE

One-way ANOVA results for types of community on the TPB variables

	IN		BE		AT		SN		PBC	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Green Community	4.071	0.802	3.592	0.968	4.392	0.738	4.133	0.754	4.030	0.73
Normal Community	3.767	0.857	3.212	1.001	4.013	0.767	3.629	0.682	3.548	0.62
F	13.604***		15.04***		25.580***		34.573***		35.684**	

*Note. *** p < 0.001. TPB = Theory of Planned Behavior, IN = Intention, BE = Behavior, AT = Attitude, SN = Subjective Norm, PBC = Perceived Behavior Control*

IV. Discussion

In this study, the application of big data technology and smart waste sorting devices in green demonstration communities has shown significant results. Compared to ordinary communities, residents in green demonstration communities demonstrate greater enthusiasm and consistency in their waste-sorting behaviors and attitudes. This is closely linked to the big data-driven management systems' real-time feedback and reward mechanisms. Previous research has shown that real-time feedback plays a crucial role in improving driving behaviors and reducing accidents caused by driver errors (Thakrar et al., 2023). Similarly, this study demonstrates that real-time feedback in waste sorting helps residents develop more responsible environmental habits, enhancing overall environmental governance.

The study also found that smart waste sorting devices and big data technology effectively improved residents' sorting of recyclable materials like plastic and cardboard and extended these habits to food waste sorting. This spillover effect suggests that environmental habits developed in one area can positively influence other related behaviors. By analyzing residents' sorting behavior in real-time, big data technology provides community managers with precise decision-making support, making management measures more effective and targeted. This data-driven management model serves as a reference template for other communities and highlights the broader potential of these technologies in environmental governance. Future research should explore how to promote these technologies in non-demonstration communities further to advance the sustainable development of the waste sorting industry.

VI. .Conclusion

In conclusion, this study highlights the significant role of big data technology and smart waste sorting devices in enhancing residents' participation in waste sorting activities within green demonstration communities. The findings reveal that these technologies not only improve waste sorting behaviors but also have potential spillover effects on other environmentally-friendly actions. These innovations provide real-time feedback, rewards, and precise management through data analysis, which contribute to more effective and targeted environmental governance. The success observed in green demonstration communities offers valuable insights for expanding similar initiatives to non-demonstration communities, ultimately promoting the sustainable development of the waste sorting industry and broader environmental protection efforts. Future research should focus on optimizing these technologies and exploring their application in diverse community settings to maximize their positive impact.

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