# Barriers to compulsory waste sorting for a circular economy in China

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## Abstract

Household waste source separation substantially reduces the amount of rubbish sent to landfills and incinerators. It enables value recovery from useful waste for transitioning to a more resource efficient and circular economy. Confronted by the severe waste management problems, China recently implemented its most strict compulsory waste sorting program in big cities to date. Despite the failures of waste sorting projects in China in the past, it is unclear what the implementation barriers are, how they interact, and how they can be overcome. This study addresses this knowledge gap through a systematic barrier study involving all the relevant stakeholders in Shanghai and Beijing. It uncovers the complex interrelationships between barriers using the fuzzy decision-making trial and evaluation laboratory (Fuzzy DEMATEL) method. “Hasty and inappropriate planning” and “lack of policy support at the grassroots level”, two new barriers that are not reported in the literature, are found to be the most influential barriers. Policy implications are discussed based on the study findings to inform the policy deliberations on the implementation of compulsory waste sorting.

**Keywords**: Circular economy, waste sorting, household waste management, municipal waste management, barrier, China.

**Article Type:** Research Article

## 1. Introduction

Municipal solid waste (MSW) is comprised of various everyday items including unconsumed food, furniture, household appliances and electronics, clothing, and packaging materials. In 2018, the volume of MSW in China reached 228.02 million tons, more than tripling that of 1990 (Tiseo, 2023). The growth of MSW has shown no sign of slowing in China due to its rapid urbanization and industrialization. At present, over 95% of MSW in China is landfilled or incinerated, causing toxic emissions and other environmental issues (He and Fu, 2021; Kurniawan et al., 2021). According to *Nature*'s recent special issue on circular economy, China's consumption of resources and the amount of waste generated pose a severe threat not only to China but also to the world's sustainability (Mathews and Tan, 2016).

Most developed countries have established a comprehensive program for sorting waste at source and recycling useful waste. In contrast, typical Chinese households mix all types of rubbish and dispose of them altogether. To divert waste from landfills and to recover useful materials, China has tried several rounds of MSW sorting pilots since 1997 (Zhuang et al., 2008). However, no city-wide implementation has succeeded. For instance, in 2000, a pilot MSW source separation program was launched in eight major cities (Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou, Nanjing, Xiamen, and Guilin). The program was heavily funded and widely promoted, but the overall performance was poor (Tai et al., 2011). In recent years, many cities have provided public rubbish bins for different types of waste, but most citizens do not throw their rubbish into the right bins. Existing waste sorting activities are mainly performed by scavengers, who search through public rubbish bins and piles of rubbish bags to pick items of high commercial value (Guo and Chen, 2022). They make a living or generate extra income by selling them to recycling businesses, but they usually disregard food waste and items of low commercial value.

Confronted by the increasingly tight landfill capacities and many other environmental problems, the Chinese central government recently started to implement compulsory waste sorting. In July 2019, Shanghai, the largest Chinese city with a population of over 26 million, started to enforce compulsory waste sorting. Shanghai's regulations require people to sort waste into four categories: dry, wet (kitchen waste), recyclable, and hazardous waste. The regulations are the most strict in China's history. Non-compliant citizens and organizations may get a fine of up to 200 and 50,000 Chinese Yuan Renminbi (RMB), respectively. Involving tens of thousands of law enforcement personnel and volunteers, the program achieved a remarkable source separation rate of 70%-80% in the first half-year (Wang et al., 2021b). In May 2020, Beijing became the second city in China to start compulsory waste sorting. It also quickly made encouraging progress by using tough policy and legislative measures and strict monitoring. However, there are signs of many residents giving up waste sorting once the monitoring efforts are eased, which was the pattern that preceded the failures of earlier implementations (Xu, 2019). Given the difficulties in sustaining the public's positive behavioral change as observed in the past, it is believed that it will take years to see how far Shanghai, Beijing and other major Chinese cities can progress in compulsory waste sorting (Wu et al., 2020; Xu, 2019).

This research aims to uncover the complex interrelationships among the barriers to compulsory waste sorting in China for recommending effective circumventing polices. Waste sorting sounds simple, but in practice it has been very hard to enforce it in China (Bian et al., 2022a; Guo and Chen, 2022). The key challenge lies in the fact that many implementation barriers are intertwined with each other, so it is difficult to address them individually. Based on the studies of the earlier MSW sorting pilots, the extant literature identified individual challenges in legislation, infrastructure, coordination mechanisms, environmental education, and public participation (Tai et al., 2011; Xiao et al., 2017). However, there is a lack of understanding of how the individual barriers interact from a systems perspective for uncovering

the root causes of the public's resistance to waste sorting. Furthermore, the recent boom of e-commerce in China has brought about new challenges in the huge amount of packaging waste, and the public's awareness of environmental issues has increased. Therefore, there is a need to conduct an up-to-date and in-depth investigation of barriers to the newly launched compulsory waste sorting program. We meet this need by addressing the following research questions:

- What are the key barriers to effectively implementing the latest compulsory waste sorting in China?
- How do the barriers interact with each other?
- How can the root causes be identified and overcome?

This research employs a mixed-methods approach. The first research question is answered by a qualitative study. We first compiled an initial list of barriers based on the extant literature. We then revised and substantiated the list based on 45 semi-structured interviews with multiple types of research participants in Shanghai and Beijing. The second and third research questions are answered by quantitative analyses. We surveyed 36 respondents who were knowledgeable on MSW sorting. Their diverse backgrounds represented the local governments, residential property managers, non-governmental organizations (NGOs), waste management service providers, waste management researchers, and community residents. They quantified the impact relationships between the barriers identified in the qualitative phase. The obtained quantitative data was analyzed by utilizing the fuzzy decision-making trial and evaluation laboratory (Fuzzy DEMATEL) technique, a scientific multi-criteria decision-making technique. In recent years, Fuzzy DEMATEL has been proved useful in systematically analyzing the complicated relationships between factors, especially those involving human behaviors which are inherently uncertain, vague, and even biased (Farooque et al., 2019; Virmani et al., 2022).

This research generates new knowledge which can be a timely aid in China' sustainable development. The resulting policy recommendations, if implemented, can help China reduce

the consumption of virgin natural resources and the environmental impact of its MSW. In addition, the research findings offer valuable insights to many other developing countries which also need to implement MSW sorting. Some of the policy recommendations may be widely applicable in other contexts, especially where the public's behavioral patterns are similar to those in China. Therefore, our study findings have great potential to contribute to achieving the United Nations' sustainable development goals.

The rest of this paper is organized as follows. Section 2 reviews the relevant literature on MSW management and household waste sorting. Section 3 outlines the methodology and data collection procedures. Section 4 reports study results and findings. Section 5 discusses policy implications. Section 6 concludes the study.

## 2. Literature review

### *2.1 Waste sorting management practices*

The World Bank reported that the amount of global waste generation will grow to 3.4 billion tons per year by 2050, 70% higher than in 2018 (Kaza et al., 2018). As an indispensable part of the circular economy, MSW sorting can refine waste classification and reprocessing to achieve waste minimization, resource recovery, non-hazardous treatment, and ultimately 'zero waste' (Gómez-Sanabria et al., 2022). Specifically, it can reduce the amount of land that is occupied by incinerators and landfill sites and reduce harmful emissions. The sustainable disposal of food waste can produce organic fertilizer for use in agricultural production. In the case of recyclables, the sorted waste can be reprocessed for building circular supply chains (Zhang et al., 2021b).

Many countries and regions have experimented with waste sorting practices. Typically, the implementation of waste separation can be top-down, with government departments coordinating the program, defining categories for separation, and providing appropriate

separation facilities (e.g. waste collection points) and incentives (Bian et al., 2022a; Xiao et al., 2020). Depending on the level of sophistication, the norms for waste sorting can be presented in granular dimensions, which require not only government guidance but also matching voluntary participation and sustainable behavioral norms (Guo and Chen, 2022). Alternatively, the promotion of waste sorting can be bottom-up, e.g. led by communities, NGOs and volunteers, to form social norms and gradually develop a broad base (Govindan et al., 2022). These stakeholder groups often have more community experience and can effectively mobilize grassroots participation. Especially in the early stages of waste separation policy implementation, these stakeholders are able to articulate the policy requirements and guide the public in waste separation (Zelenika et al., 2018).

The long-standing research interest in sustainable MSW sorting can be found in different perspectives. Early research focused on factors that influence participation in waste sorting practices, i.e. the micro-perspective of individual participation (Tonglet et al., 2004). These environmental behavioral perspectives can be determined by different factors such as individual awareness (Liu et al., 2022), social norms (Govindan et al., 2022), policy constraints (Bian et al., 2022a), and incentives (Li et al., 2017). It is important to note that these factors interact with each other as waste sorting needs holistic planning and active participation of all members.

Conversely, from a macro perspective, some studies examine MSW sorting from the policy intervention orientation. For example, the deposit system is prevalent in Europe, whereby consumers pay a deposit on the purchase of products, which is not refundable until the recyclable (e.g. PET bottle) is returned to a designated recycling channel (Pires et al., 2011). In particular, reverse vending machines are the channels to enable efficient collection of recyclables, although this involves expensive investments in equipment (Korucu et al., 2016). Similarly, extended producer responsibility (EPR) systems emphasize the lifecycle

responsibility for waste disposal borne by producers, who must provide (in)tangible resources for waste collection and removal (Cai and Choi, 2019). In addition, the 'certain time, certain place' is known as an efficient policy to reduce monitoring costs, as only set times and locations are available for waste drop-off (Bian et al., 2022a).

### *2.2 Barriers to sustainable MSW sorting*

MSW sorting is difficult to implement and sustain, requiring deep understanding on the interactions of multiple influential factors (Guo and Chen, 2022; Pedersen and Manhice, 2020). This section presents the key barriers to sustainable MSW sorting and they are summarized in Table 1 in the following dimensions.

*Accountability governance*: Confusion in roles and responsibilities can lead to dysfunctional accountability governance. Each stakeholder of a MSW sorting program needs to know its responsibilities and be held accountable. In the early stages of waste sorting implementation, the government relied on the services purchased from recycling companies and NGOs, who could play educational and supervisory roles (Arantes et al., 2020). The goal is for residents to be able to segregate their own waste without too much supervision. However, the common problem existed in the waste sorting pilot projects in China was a sharp decline in waste sorting performance when supervision is removed (Guo and Chen, 2022), suggesting ineffective accountability governance.

*Incentives*: Incentive systems need to include reasonable positive incentives as well as penalties. For governments, substantial financial support, such as providing monetary incentives, is not a long-term solution (Li et al., 2017). And, a penalty system requires a great deal of regulation, and the burden of excessive regulation is not conducive to encouraging waste separation (Guo and Chen, 2022).

*Information system:* MSW sorting involves the recycling chain for different waste categories and access to waste flow data is crucial (Zhou et al., 2021). However, access to and

integration of waste stream information is a major barrier. Specifically, some traditional recycling companies, especially small and medium-sized enterprises (SMEs), do not have complete information on waste, and information asymmetry is often leveraged as a competitive advantage in waste trade (Xie et al., 2022). For the government, it is difficult to make decisions without comprehensive data, especially since there is no unified database to visualize waste information (Gong et al., 2021; Wen et al., 2021).

*Infrastructure*: MSW sorting requires a combination of physical and institutional infrastructure. Many regions are gradually rolling out smart waste sorting equipment, such as smart recycling bins (Zhang et al., 2019). However, most regions with poorly managed waste segregation still lack supporting facilities, e.g. the lack of drop-off facilities, or the back-end processing facilities have limited capacity to process the collected waste. Even worse, an incomplete recycling transport system results in mixed transport after sorting, undermining efforts to separate at the source. In developing countries, widespread informal recycling networks can create confusing market competition, especially when high-value recyclables are collected but not low-value recyclables such as kitchen waste (Wen et al., 2021). Complex localization issues also need to be considered (de Sousa Dutra et al., 2018). The construction and renovation of facilities need to be agreed with the residents and property managers, and accordingly the locations of the bins need to be communicated in advance to avoid community disputes.

*Legislation and policy*: compulsory legislation is seen as an important driving force. However, in many areas, waste sorting is seen voluntary, i.e., it is encouraged rather than mandatory. In other words, there is a lack of legislative backing and limited enforcement by the relevant authorities (Guo and Chen, 2022; Wang et al., 2021b). Depending on the stage of implementation of waste sorting, earlier plans may have been too broad and not detailed with specific policies (Huang et al., 2022).

*Policy enforcement*: Top-down waste sorting policy transfer is a common management approach. For example, in China, waste sorting is cascaded down from municipal government, district government, and street agency to community. The main policy implementers are those in the grassroots government such as the street agency, who usually receive the policy from the higher-level government and guide the residents to implement it (Guo and Chen, 2022). Accordingly, policy implementation needs to be subject to appraisal, as the legislation stipulates that this is an indicator for administrative appraisal. However, waste sorting implementers tend to maximize key performance indicators (KPIs) in response to assessments rather than encouraging residents to participate (Bian et al., 2022a).

*Propaganda*: Common methods of propaganda include distributions of brochures, banners, doorstepping, and educational activities (Dai et al., 2015). The essence of awareness-raising is to improve awareness and enforcement of waste separation. In practice, the effectiveness of campaigns is difficult to quantify and requires a significant investment of resources. People are initially receptive to these education and awareness campaigns, but the extent to which they are implemented requires complementary programs (Huang et al., 2022).

*Recycling chain coordination*: Waste sorting requires the combined efforts of the members of the recycling chain. The need to sort at source is matched by the need to process at the back end (Arantes et al., 2020). And, in developing countries, informal recyclers still bear the brunt of collection responsibilities. These scattered informal recyclers need to be properly integrated into the recycling network (Xie et al., 2022).

In summary, the barriers listed in Table 1 are relevant to MSW sorting in China. However, most of them are based on the past waste sorting pilot projects so they may be outdated. Existing studies are scattered to discuss factors that contribute to waste management challenges rather than specifically focusing on waste sorting. Considering that the current compulsory waste sorting initiatives still face many obstacles in China, a holistic approach is needed to

identify and extend the understanding of implementation barriers (Guo and Chen, 2022). More importantly, the interrelationship of these barriers needs to be investigated, as the difficulties in implementation are partly caused by the interactions among multiple factors. To address the knowledge gap, this research conducts a systematic and up to date study of the main barriers to the latest compulsory waste sorting in China, analyze their interrelationships, and offer policy guidance.

**Table 1. Barriers to sustainable MSW sorting in the extant literature**

| Dimension | Main barriers | Explanation | References |
|---|---|---|---|
| Accountability governance | • Accountability allocation<br>• Confusing roles and responsibilities | Lack of clarity in roles and responsibilities, involving task overlap between the involved stakeholders and unclear accountability mechanism. | (Arantes et al., 2020; Bian et al., 2022a; Wang et al., 2021b) |
| Incentives | • Lack of incentive systems<br>• Inaccurately positioned incentive systems<br>• Recycling behavior inconsistency | Lack of sustained incentives for residents to participate in waste separation on their own initiative rather than relying on financial incentives or mandatory administration. | (Bian et al., 2022a; Li et al., 2021; Lu and Sidortsov, 2019) |
| Information system | • Lack of information platform<br>• Nontransparent waste flows<br>• Information asymmetry in recycling chain | Lack of standards to collect and integrate data related to waste flows, which may cause information asymmetry issue. | (Tong et al., 2018; Wang et al., 2021a; Zhang et al., 2019) |
| Infrastructure | • Institutional infrastructure<br>• Physical infrastructure<br>• Complicated localization | Complex issues with institutional infrastructure (e.g. culture, environmental education, waste awareness, social norms) and physical infrastructure (e.g. waste bins, processing facilities, waste transportation, disposal plants). Different regions and communities may have unique localization issues. | (de Sousa Dutra et al., 2018; Matiiuk and Liobikienė, 2021; Sewak et al., 2021) |
| Legislation and policy | • Lack of supporting legislation<br>• Lack of refined policy<br>• Outdated information strategy | Lack of detailed and feasible incentive system; Lack of supporting enforcement policy; limited enforcement powers and penalties. | (Govindan et al., 2022; Guo and Chen, 2022; Wang et al., 2021b) |
| Policy enforcement | • Drift in policy implementation<br>• Difficulties in policy implementation<br>• Over-emphasis on KPIs | Policy implementation and evaluation is cascaded top-down, while lower-level implementers overly pursue KPI targets at the expense of actual results. | (Bian et al., 2022a; Cudjoe et al., 2020; Tian et al., 2022; Wang et al., 2021a) |
| Propaganda | • Insufficient investment in publicity<br>• Ineffective promotion<br>• Publicity with limited effectiveness | Some areas have inadequate or ineffective propaganda (e.g., banner displays, word of mouth), and the actual impact of the propaganda is difficult to quantify. | (Arantes et al., 2020; Dai et al., 2015; Huang et al., 2022; Li and Wang, 2021) |
| Recycling chain coordination | • Uncoordinated stakeholders (informal sectors, NGOs, volunteers)<br>• Lack of cooperation from key stakeholders<br>• Informal recycling group engagement | The members of the waste recycling network are fragmented in their operations, and they do not cooperate with each other. Also, there are difficulties in engaging informal groups in developing countries. | (Arantes et al., 2020; Dhokhikah et al., 2015; Guo and Chen, 2022; Xie et al., 2022) |

## 3. Methodology and data

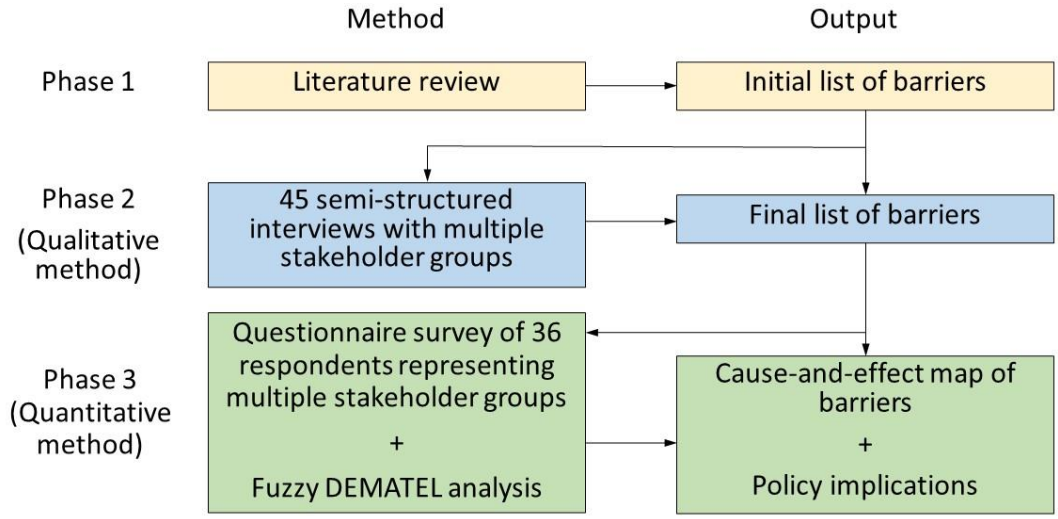


**Figure 1. Research methodology**

Figure 1 outlines the research methodology. Phase 1 established an initial list of barriers to waste sorting in China (Table 1) based on the review of literature presented in the preceding section. Phase 2 included 45 semi-structured interviews with multiple stakeholder groups who were involved in the latest compulsory waste sorting in Shanghai and Beijing. This stage finalized a list of 13 up to date barriers that were most important. Phase 3 conducted a questionnaire survey of 36 respondents from multiple stakeholder groups and the survey data was analyzed by using the Fuzzy DEMATEL method. This phase generated a cause-and-effect map of barriers. Based on the results and findings, we discuss policy implications for overcoming barriers to waste sorting. The following subsections provide details related to study methods and data.

### *3.1 Finalizing the study barriers*

This section explains Phases 1 and 2 of the research to finalize the barriers. As mentioned earlier, we conducted a literature review to compile an initial list of barriers as provided in Table 1. We then translated the list into Chinese. Note that all the researchers are fluent in both English and Chinese. Then, the research team used its extensive professional network in the government and the recycling sectors to recruit research participants. One researcher conducted

face-to-face semi-structured interviews in Shanghai and Beijing between October 2021 and January 2022. To ensure data validity, we interviewed a wide range of stakeholders as presented in Table 2. The interviewees were asked about what barriers had been preventing the latest compulsory waste sorting program from achieving an ideal outcome. They were requested to talk about barriers related to all relevant stakeholders and cover both the soft side and the infrastructure/technology side. The interview questions are provided in Supplementary Material (Appendix A).

The data collection took place in Shanghai first and stopped after 33 interviews when data saturation was observed, i.e., interviewing more research participants no longer provided new insight. In Beijing, we followed the same procedure to conduct 12 interviews. It turned out that the data collected in Beijing was very similar to that in Shanghai, so we did not try to recruit more interviewees in Beijing. Data homogeneity is not a surprise in this study because the latest waste sorting policy was initiated by the Chinese central government and there were no major differences in its implementation in Shanghai and Beijing.

**Table 2. Profile of interviewees**

| **Role/Organization type** | **Number of interviews** |
|---|---|
| Recycling company | 9 [CEO (3); Manager (6)] |
| NGOs | 7 (Funder (4); Officer (3)) |
| University professors/researchers | 7 |
| Government | 4 [Waste sorting program manager (2); official (2)] |
| Industry/Professional association | 2 [Deputy Secretary] |
| Scavenger/Cleaner | 5 |
| Resident | 11 |
| **Total** | **45** |

Based on the interview data, the researchers revised the initial list of barriers to finalize a list of 13 most important barriers to the latest compulsory waste sorting in China after iterative discussions. This finalization process also helps the questionnaire respondents to understand the barriers better and avoid confusions. Each of these barriers is explained in Table 3.

**Table 3. Finalized barriers for the latest compulsory waste sorting in China**

| Barriers | Explanations | Supporting evidence/ examples |
|---|---|---|
| **B1 - Relapse in waste sorting behavior** | Resident participation was active in the initial stage, but they cannot maintain their waste sorting behavior over long term. | The participation of some residents became inconsistent after the supervision was reduced (Govindan et al., 2022; Xu, 2019). |
| **B2 - Confusion in roles and responsibilities** | The roles and responsibilities are not clearly defined and communicated to all the stakeholders involved in waste sorting. | The misunderstanding of roles and responsibilities caused these residents not taking responsibility for waste sorting (Arantes et al., 2020). Some residents thought that cleaners or third-party service providers should be responsible for waste sorting and their salaries were covered by property management fees (Bian et al., 2022a). |
| **B3 - Inconvenience** | Waste sorting requires citizens to spend time on separating waste in daily living. Some residents complain about the inconvenience caused by the widely adopted 'certain time, certain place' policy in the latest compulsory waste sorting program. | The 'certain time, certain place' policy stipulates that only designated times and locations are allowed for disposing of rubbish (Bian et al., 2022b). Due to conflicting work schedules, some residents are not able to throw away rubbish. Walking distances have become much greater in large residential communities and this issue is more pronounced for the elderly who have mobility issues. |
| **B4 - Ineffective incentive systems** | The current incentives offered for waste sorting are not sufficient to induce a behavioral change for most citizens and reward incentives are not a long-term solution. | The initial incentivizing attempt, the 'Green Account' policy, was a huge financial burden (Lu and Sidortsov, 2019). The new 'Internet+' recycling mode is only for recyclables but not for other waste categories. Both incentive systems had limited participation (Gong et al., 2021; Tong et al., 2018). |
| **B5 - Ineffective propaganda and public education** | The propaganda methods used in some areas are inefficient or outdated, and educational outreach is limited in some regions. | Some street agencies mainly relied on publicity posters posted on the community walls and publicity brochures distributed to residents' mailboxes, but many residents do not pay attention to them at all. Some areas adopted doorstepping for publicity, but it required a lot of human resources and personnel management (Dai et al., 2015). |
| **B6 - Complicated localization** | Localization refers to the unique problems that exist in different regions and communities such as spacing limitations for installing waste management facilities and floating population. | The common localization issues are related to renovation and construction of waste compartments, waste collection site selection, and a large floating population (Xu et al., 2021). |
| **B7 - Lack of policy support at the grassroots level** | The legislation for waste sorting have been developed at the city level, but there is a lack of supporting policy measures and legislation at the grassroots level to guide practice. | Lack of fine-grained policy guidance for the implementation at the grassroots level. There is a lack of clarity about specific support for property managers, inclusion of informal recyclers, and division of responsibilities between volunteers and cleaners (Arantes et al., 2020; Guo and Chen, 2022). |

| | | |
|---|---|---|
| **B8 - Lack of coordination among stakeholders** | It is inherently challenging to coordinate the efforts of a wide range of stakeholders who are relevant to waste sorting. | The objectives of a diverse range of stakeholders (residents, property managers, city councils, street agencies, waste transportation providers, recycling businesses, community volunteers, media, researchers, educational institutions, and NGOs) are not in complete agreement with each other's (Guo and Chen, 2022; Zhou et al., 2021). |
| **B9 - Inadequate physical infrastructure** | Certain physical infrastructure is not ready or does not have sufficient capacity to meet the compulsory waste sorting requirement. | Waste sorting requires the availability of multiple types of waste bins or compartments at the right locations, the surveillance hardware systems for monitoring non-compliance, appropriate waste transport vehicles, sanitized landfill sites, and a variety of recycling operations for value recovery from waste (Wang et al., 2021b). |
| **B10: Hasty and inappropriate planning** | The policy push from the central government and city councils had a very ambitious timeline to see success. | Such a timeline was found to be unrealistic for constructing the required facilities and many design and planning issues surfaced at a later stage due to a hasty implementation (Bian et al., 2022a; Xu et al., 2021). |
| **B11 - Funds allocation issues** | Waste sorting requires funding support for a wide range of activities, and funds are not always allocated properly, and errors can be made in decision-making. | The government may have spent too much on publicity and education, but the funds allocated for facility renovation are insufficient (Guo and Chen, 2022). |
| **B12 - Loopholes in performance management:** | The central and city-level governments set evaluation indicators, i.e., key performance indicators (KPIs), which can be manipulated to appear excellent, but the actual performance is unsatisfactory. | Most of KPIs measured by the central and city level governments are quantitative, for example, number of waste bins deployed, recycling rate, and participation rate. Some residential communities hired cleaners to help with waste sorting to meet the KPIs (Bian et al., 2022a). |
| **B13 - Lack of public engagement in policy making** | Public consultation related to environmental policies tends to be limited and hasty. | The public is more willing to be engaged and support policy implementation if they are consulted in the policy-making stage. Limited engagement discourages many members of the public from taking ownership of the waste sorting policies which is a barrier to policy implementation (Bian et al., 2022a; Farooque et al., 2019). |

Most of these 13 barriers were at least partially addressed in the literature. For example, B1 (Relapse in waste sorting behavior) is related to 'Recycling behavior inconsistency' as outlined in Table 1. However, three barriers are new, and they are B10 (Hasty and inappropriate planning), B7 (Lack of policy support at the grassroots level), and B11 (Funds allocation issues). Our insights from research participants suggest this is because the latest compulsory waste sorting in Shanghai and Beijing is unprecedented in implementation scale and speed, and the city councils have committed a huge amount of financial resources. This confirms that this study is necessary for providing the up-to-date knowledge on waste sorting barriers.

### *3.2 Survey data collection*

Based on the 13 barriers identified above, we designed a questionnaire for rating the effects of barriers on each other. The core element of the questionnaire is a form for rating the interrelationships between barriers, which is provided in Supplementary Material (Appendix B). We recruited 36 survey respondents who were knowledgeable on MSW sorting to ensure the quality of the data and the validity of the results. Their diverse backgrounds represent residential community/property managers (4), waste management researchers/consultants (5), governments (5), NGOs (7), street agencies (4), waste management enterprises (6), and residents (7). Table 4 presents the profile of survey respondents including information on the years of professional experiences except for residents. Participation in the research was voluntary. The research participants were assured of the confidentiality of their data and their use for academic research purposes only.

Our survey sample size is larger than many DEMATEL studies that are of the same nature. For example, Virmani et al. (2022)'s study about net zero transition justified a sample size of eight based on their review of similar studies. We obtained data from a wide range of stakeholders to mitigate the negative effects of potential bias from any stakeholder group. Some recent DEMATEL studies also surveyed multiple stakeholder groups, for example, Zhang et

al. (2019)'s study on barriers to smart waste management and Farooque et al. (2020)'s study on barriers to blockchain technology adoption. However, both studies surveyed only one expert for representing a stakeholder group while we had multiple respondents for each group.

**Table 4. Profile of survey respondents**

| Stakeholder group | No. | Professional experiences |
|---|---|---|
| Community/Property managers (4) | 1 | 4-7 years |
| | 2 | 1-3 years |
| | 3 | 4-7 years |
| | 4 | 4-7 years |
| Researcher/Consultant (5) | 5 | over 13 years |
| | 6 | 8-12 years |
| | 7 | over 13 years |
| | 8 | over 13 years |
| | 9 | 1-3 years |
| Government (3) | 10 | 8-12 years |
| | 11 | over 13 years |
| | 12 | over 13 years |
| NGO (7) | 13 | 4-7 years |
| | 14 | 8-12 years |
| | 15 | 8-12 years |
| | 16 | 8-12 years |
| | 17 | 4-7 years |
| | 18 | 1-3 years |
| | 19 | 8-12 years |
| Street agency (4) | 20 | 1-3 years |
| | 21 | 4-7 years |
| | 22 | 4-7 years |
| | 23 | 4-7 years |
| Waste management enterprise (6) | 24 | 8-12 years |
| | 25 | over 13 years |
| | 26 | 4-7 years |
| | 27 | 8-12 years |
| | 28 | 1-3 years |
| | 29 | 4-7 years |
| Resident (7) | 30-36 | |

We performed comprehensive preliminary analysis to check data quality. Data from the respondents in Shanghai and Beijing was compared. Like qualitative data, the quantitative survey data from the two cities showed no obvious difference when we compared their fuzzy DEMATEL analysis results. We also performed preliminary analysis using data from across

all stakeholder groups and we did not find any outlier. This proves that there is good consensus among all stakeholder groups on the relationships between barriers. Therefore, it is valid to aggregate the data from all the 36 respondents for fuzzy DEMATEL analysis.

### *3.3 Fuzzy DEMATEL method*

The DEMATEL method is a scientific multi-criteria decision-making technique. It is useful for analyzing the complicated interrelationships among factors (Bakir et al., 2018; Chauhan and Singh, 2021; Venkatesh et al., 2017). Given that human judgement inevitably involves subjectivity, vagueness, and potential bias (Wu and Lee, 2007), researchers developed multiple variants of the standard DEMATEL method, among which the grey-based DEMATEL and Fuzzy DEMATEL are most widely used (Bai and Sarkis, 2013; Farooque et al., 2019; Tseng et al., 2021). These two variants follow similar methodological steps, but the Fuzzy DEMATEL is slightly more sophisticated, using three-dimensional fuzzy numbers (e.g., 0.75, 1, 0.25) other than two-dimensional grey numbers (e.g., 0.5, 0.25) (Zhang et al., 2021a). This study uses the fuzzy DEMATEL method and outline its technical procedures (Farooque et al., 2019; Venkatesh et al., 2017) below.

***Step 1*:** Construct a pairwise comparison matrix for barriers

Research participants rate the effect of barrier *i* on barrier *j* (Rating scale 0-4: 0 represents no effect; 4 represents the greatest effect).

***Step 2*:** Develop the fuzzy initial direct relation matrix (A)

This step uses triangular fuzzy numbers (TFNs) to capture the fuzziness in human judgments (Seçme et al., 2009). Each TFN is expressed as a triplet (e, f, g), in which e, f, and g specifies the smallest possible, the most promising, and the largest possible value, respectively. Table 5 presents the fuzzy linguistic scale used (Venkatesh et al., 2017; Wu and Lee, 2007) for converting effect ratings to TFNs.

**Table 5. Fuzzy linguistic scale**

| Effect rating | Description | Equivalent TFNs |
|---|---|---|
| 0 | No influence (No) | (0,0,0.25) |
| 1 | Very low influence (VL) | (0,0.25,0.5) |
| 2 | Low influence (L) | (0.25,0.5,0.75) |
| 3 | High influence (H) | (0.5,0.75,1.0) |
| 4 | Very high influence (VH) | (0.75,1.0,1.0) |

Let $x_{ij}^{k} = e_{ij}^{k}, f_{ij}^{k}, g_{ij}^{k}$ ($1 \leq k \leq K$; K denotes the sample size of research participants) represents the $k^{th}$ research participant's rating on the effect of barrier *i* on barrier *j*. Assuming there are n barriers in total, the pairwise comparison would lead to an n×n matrix.

$$a_{ij} = \frac{1}{k\sum x^{k_{ij}}} \tag{1}$$

The defuzzification process, defined by equation (2), is then followed to convert the fuzzy numbers to crisp numbers to enable matrix operations.

$$I_T = \frac{1}{6}(e + 4f + g) \tag{2}$$

***Step 3:*** Develop the normalized initial direct relation matrix (D)

$$m = \min\left[\frac{1}{\max\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max\sum_{i=1}^{n}|a_{ij}|}\right] \tag{3}$$

$$D = m \times A \tag{4}$$

***Step 4:*** Compute the total relation matrix

$$T = (I - D)^{-1} \tag{5}$$

Where I: Identity matrix; T: Total relation matrix $\left[t_{ij}\right]_{n\times n}$

***Step 5:*** Calculate the sum of rows (R) and the sum of columns (C)

$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \tag{6}$$

$$C = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \tag{7}$$

R represents the overall effect that barrier *i* has on barrier *j*. C stands for the overall effect experienced by barrier *i* from barrier *j*.

***Step 6:*** Generate a cause-and-effect map

The data set (R+C; R-C) is used to generate a cause-and-effect map. R+C values on the horizontal axis measure the prominence of a barrier because they represent total effects in terms of influenced and influential power. R-C values on the vertical axis measure the cause-effect relationships. Barriers that are associated with a positive R-C value are considered cause barriers; while those that have a negative R-C value are effect barriers (Lin, 2013; Wu, 2012). In addition, significant relationships between barriers can be indicated by arrows on the cause-and-effect diagram to highlight their interdependence.

## 4. Results and findings

**Table 6. Total relation matrix**

| | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** | **B13** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | 0.16 | 0.15 | 0.17 | 0.14 | 0.19 | 0.15 | 0.15 | 0.18 | 0.16 | 0.12 | 0.13 | 0.14 | 0.15 |
| **B2** | **0.32** | 0.18 | 0.24 | 0.21 | **0.30** | 0.19 | 0.24 | **0.30** | 0.24 | 0.18 | 0.22 | 0.24 | 0.22 |
| **B3** | 0.27 | 0.16 | 0.14 | 0.15 | 0.22 | 0.16 | 0.16 | 0.19 | 0.19 | 0.12 | 0.15 | 0.15 | 0.16 |
| **B4** | 0.25 | 0.18 | 0.17 | 0.12 | 0.22 | 0.14 | 0.16 | 0.20 | 0.16 | 0.13 | 0.17 | 0.17 | 0.16 |
| **B5** | 0.26 | 0.18 | 0.19 | 0.15 | 0.16 | 0.15 | 0.15 | 0.19 | 0.16 | 0.12 | 0.14 | 0.15 | 0.17 |
| **B6** | **0.30** | 0.23 | 0.25 | 0.19 | 0.28 | 0.13 | 0.20 | 0.25 | 0.23 | 0.15 | 0.18 | 0.18 | 0.20 |
| **B7** | **0.34** | 0.28 | 0.27 | 0.24 | **0.32** | 0.20 | 0.19 | **0.30** | 0.28 | 0.18 | 0.24 | 0.25 | 0.24 |
| **B8** | **0.30** | 0.24 | 0.24 | 0.21 | 0.28 | 0.18 | 0.23 | 0.20 | 0.24 | 0.18 | 0.21 | 0.22 | 0.20 |
| **B9** | 0.28 | 0.17 | 0.24 | 0.15 | 0.24 | 0.17 | 0.17 | 0.20 | 0.14 | 0.14 | 0.16 | 0.17 | 0.16 |
| **B10** | **0.33** | 0.27 | 0.26 | 0.24 | **0.32** | 0.20 | 0.27 | **0.31** | 0.28 | 0.14 | 0.24 | 0.26 | 0.25 |
| **B11** | 0.26 | 0.21 | 0.22 | 0.22 | 0.27 | 0.17 | 0.21 | 0.25 | 0.25 | 0.14 | 0.14 | 0.19 | 0.17 |
| **B12** | 0.26 | 0.22 | 0.19 | 0.18 | 0.24 | 0.15 | 0.21 | 0.25 | 0.20 | 0.15 | 0.18 | 0.14 | 0.17 |
| **B13** | 0.27 | 0.19 | 0.23 | 0.18 | 0.26 | 0.15 | 0.18 | 0.21 | 0.19 | 0.14 | 0.15 | 0.18 | 0.13 |

Table 6 presents the obtained total relation matrix. The mean and standard deviation of the numbers in the total relation matrix are 0.20 and 0.05, respectively. Following Li and Tzeng (2009), we derived a threshold value 0.28 by adding 1.5 times standard deviations to the mean.

Numbers greater than the threshold value in Table 6 represent significant causal relationships and they are highlighted using bold texts.

Figure 2 is the cause-and-effect diagram. All significant causal relationships are mapped using arrows, pointing from a cause barrier to an effect barrier. The three main cause barriers (highest R-C values) are B10 (Hasty and inappropriate planning), B7 (Lack of policy support at the grassroots level), and B6 (Complicated localization). The cause barriers have a fundamental effect on the system as they represent root causes to resistance to compulsory waste sorting. They should be dealt with thoroughly to ensure the long-term success of the waste sorting program.

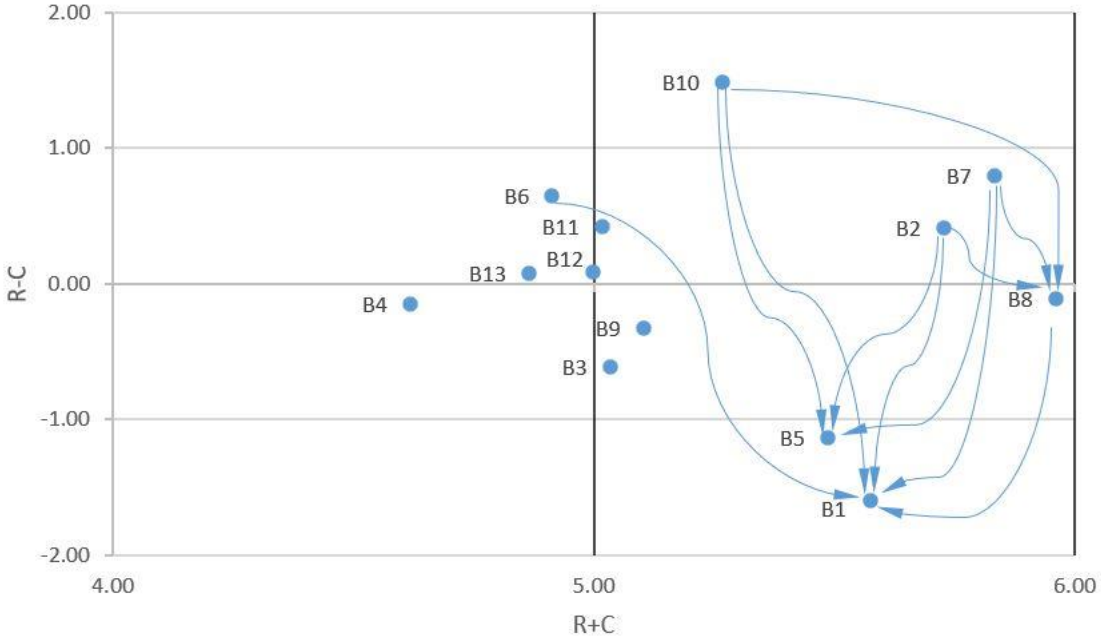


**Figure 2. Cause-and-effect diagram**

The three most prominent barriers (highest R+C values) are B8 (Lack of coordination among stakeholders), B7 (Lack of policy support at the grassroots level), and B2 (Confusion in roles and responsibilities). The prominent barriers have the greatest immediate effect on the system, so they require urgent attention. Waste sorting performance can leapfrog if the prominent barriers are overcome.

The two most obvious effect barriers (lowest R-C values) are B1 (Relapse in waste sorting behavior) and B5 (Ineffective propaganda and public education). This finding is in line with common sense. According to the effect relationships indicated by arrows in Figure 2, B1 (Relapse in waste sorting behavior) is mainly caused by B10 (Hasty and inappropriate planning), B7 (Lack of policy support at the grassroots level), B6 (Complicated localization), B2 (Confusion in roles and responsibilities), and B8 (Lack of coordination among stakeholders). B5 (Ineffective propaganda and public education) is mainly caused by B10 (Hasty and inappropriate planning), B7 (Lack of policy support at the grassroots level), and B2 (Confusion in roles and responsibilities). If their underlying causes are addressed, these effect barriers will automatically disappear or be relieved.

The two new barriers that are not reported in the literature, B10 (Hasty and inappropriate planning) and B7 (Lack of policy support at the grassroots level), are found to be very influential in the latest compulsory waste sorting in Shanghai and Beijing. This new and significant finding affirms the value of this study and accurately reflects the reality in China: the latest compulsory waste sorting was driven by the central government with an unprecedented determination through a top-down approach. There was a great sense of urgency in the policy drive so a short timeframe was given for the implementation. However, the situations at the grassroots level are very complex and difficult to sort out in a haste. It also takes a long time for the public to take more ownership of waste sorting and form a more responsible behavior.

## 5. Policy implications

The results and findings presented above have important policy implications. First, both the national policymakers and local city councils should not underestimate the complexity and challenges in implementing compulsory waste sorting. Waste sorting appears to be a trivial task in daily living, so its implementation challenges had not been thoroughly studied and

understood, which leads to B10 (Hasty and inappropriate planning). On one hand, the national policymakers were overly ambitious and did not give sufficient time for the local city councils to implement the new policy (Bian et al., 2022a). On the other hand, local city councils should learn from the lessons in Shanghai and Beijing to be more proactive in planning (Wang et al., 2021b). For example, some back-end recycling facilities require substantial investments and at least several years to build. There is a need for scientific planning in their capacities and construction. Promoting a positive behavior change is subject to resistance to change and requires support from enabling physical and institutional infrastructures. Most Chinese people don't have the habit of sorting rubbish before a disposal. Such deep-rooted habits are likely to spring back once the external pressures are reduced. A sustained waste sorting program must effectively use a diverse range of propaganda and public education methods to reshape the mindset of residents. Both positive and negative incentives can be used to encourage pro-environmental behaviors and deter irresponsible behaviors, respectively.

Second, clear and simple grassroots level policies and guidelines are crucial for compulsory waste sorting. This research finds that B7 (Lack of policy support at the grassroots level) is both a key cause barrier and a prominent barrier. Waste sorting is a new way of life for most Chinese citizens. The city councils, street agencies, NGOs, property management entities and resident committees all lack experiences in defining the roles and responsibilities associated with waste sorting. The problem is exaggerated by complex localization and the involvement of multiple stakeholders. Our field data collection suggests that many residents still had the misconception that waste sorting is voluntary, and the final responsibility resides with the property managers and their hired cleaners. This misunderstanding must be cleared. It is widely acknowledged that the 'certain time, certain place' policy reduces the supervision cost (Bian et al., 2022b), but still, it is unclear whether it should be the government or the property manager responsible for funding the on-going supervision activities which can be

costly over long term. The city councils must listen to the voices of the involved stakeholders to devise clear and fair guidelines at the grassroots level (Arantes et al., 2020).

Last but not least, the city councils need to institutionalize an effective coordination mechanism for overcoming the prominent barrier B8 (Lack of coordination among stakeholders). The implementation of waste sorting involves a wide range of stakeholders whose tasks and priorities are not necessarily aligned with each other all the time (Guo and Chen, 2022). Now, NGOs, property managers, street agencies and resident committees all could be coordinating the efforts of many depending on the dynamics in residential communities. It is often a grey area when it comes to who should be responsible for coordination among stakeholders. We suggest property management entities be assigned this responsibility because they oversee the daily waste disposal and collection activities, and they are a bridge between street agencies and residents. However, it must be financially compensated for the new responsibility; otherwise, many property management entities will not be willing to allocate resources for the job. In most communities, property managers charge residents for waste sorting services, so residents expect the job of sorting waste to be the responsibility of the property managers. However, the latest compulsory waste sorting policy puts more coordination responsibility on property managers. Currently, government funding supports mainly go to the street agencies and usually, these funds are not given directly to property managers. Street agencies usually give help to constructing hardware facilities for waste sorting, but there is no subsequent funding support for managing waste sorting activities by property managers. There is a need to formalize agreements between city councils, street agencies, and property management entities on the funding allocation.

## 6. Conclusion

The increasing MSW poses a serious challenge to the world's environmental sustainability. There is a dire need for cities to enforce waste sorting at source to facilitate a

transition to a circular economy to divert waste from landfills and incinerators. This study focuses on the latest compulsory waste sorting program launched in Shanghai and Beijing as the Chinese central government became more determined to tackle the mounting MSW challenge. The research aims to identify the barriers to compulsory waste sorting in China, how these barriers interact, and how the root causes can be found out and overcome.

This paper makes several major contributions to the literature. Firstly, it is believed to be the first systematic barrier study related to the latest compulsory waste sorting in China. After launching the initiative in Shanghai and Beijing, more Chinese cities have followed them and many more will join in the initiative. The topic is of great practical significance given the importance of transitioning to sustainable MSW management for a circular economy. Secondly, this study makes a methodological contribution. It applies a rigorous mixed-methods approach to collect both qualitative and quantitative data which ensures the validity and reliability of results. Thirdly, the study identifies two new and very influential barriers that are not found in the extant literature. 'Hasty and inappropriate planning' is found to be the most significant cause barrier. 'Lack of policy support at the grassroots level' is both a key cause barrier and a prominent barrier. These findings are valuable to inform future research in waste sorting. Finally, the research derives several important policy implications that are beneficial to the city councils in China as well as those in other countries for their implementation of household waste sorting. Another country may have a different culture and its infrastructure may not be on a par with that of China, but many of the planning matters will still be similar (e.g. the informal group issue in other developing countries) and some of the barriers identified in this study will be relevant. Therefore, the policy implications derived from this study will be useful to many developing countries.

Despite its merits, this research has its limitations. It is worth noting that our data were collected during the COVID-19 pandemic but were not much affected by strict lockdowns.

There is a need to update the research after a few years because the implementation barriers are likely to evolve over time. The research data was collected from Shanghai and Beijing, two of the most developed cities in China. These two cities are more ready to implement compulsory waste sorting because their residents are better educated than those in smaller Chinese cities. Their infrastructure for supporting waste sorting is also more developed and their city councils have more financial resources. Future research needs to be conducted in smaller Chinese cities for understanding the effects of contexts on barriers. In addition, this study focuses on waste sorting. The wider recycling chain consists of other links such as waste transportation, incineration, landfill, waste treatment and value recovery operations, and sale and reuse of recovered resources. It would be meaningful to study the whole recycling chain for maximizing the effectiveness of sustainable MSW management from a systems perspective. Also, it would be interesting to further investigate how innovative technologies are helping the implementation of MSW sorting. For example, waste sorting drop-off convenience enabled by smart waste bins (Wang et al., 2021a) and 'Internet+' solution (Tong et al., 2018), immutable data tracking and tokenization reward via blockchain technology application (Gong et al., 2022; Xie et al., 2022).

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