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An analysis of barriers for successful implementation of municipal solid waste management in Beijing: an integrated DEMATEL-MMDE-ISM approach

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Abstract

Purpose – With rapid industrialization and urbanization, municipal solid waste (MSW) management has become a serious challenge worldwide, especially in developing countries. The Beijing Municipality is a representative example of many local governments in China that are facing MSW management issues. Although there have been studies in the area of MSW management in the literature, less attention has been devoted to developing a structured framework that identifies and interprets the barriers to MSW management in megacities, especially in Beijing. Therefore, this study focuses on identifying a comprehensive list of barriers affecting the successful implementation of MSW management in Beijing.

Design/methodology/approach – Through an extensive review of related literature, 12 barriers are identified and classified into five categories: government, waste, knowledge dissemination, MSW management process and market. Using an integrated approach including the decision-making trial and evaluation laboratory (DEMATEL), maximum mean de-entropy algorithm (MMDE) and interpretive structural modeling (ISM), a conceptual structural model of MSW implementation barriers is constructed to provide insights for industrial decision-makers and policymakers.

Findings – The results show that a lack of economic support from the government, imperfect MSW-related laws and regulations, the low education of residents and the lack of publicity of waste recycling knowledge are the main barriers to MSW management in Beijing. Combined with expert opinions, the paper provides suggestions and guidance to municipal authorities and industry practitioners to guide the successful implementation of MSW management.

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Practical implications – The findings of this study can provide a reference for MSW management in other metropolises in China and other developing countries.
Originality/value – This study proposes a hybrid DEMATEL-MMDE-ISM approach to resolve the subjectivity issues of the traditional ISM approach and it analyzes the barriers that hinder MSW management practices in Beijing.

Keywords Municipal solid waste, Barrier analysis, Interpretive structural modeling, DEMATEL
Paper type Research paper

1. Introduction

With rapid industrialization and urbanization, municipal solid waste (MSW) management has become a serious challenge worldwide, especially for developing countries (Wang and Wang, 2013; World Bank, 2005; Cheng *et al.*, 2020). Developed nations hold the leading position in MSW management. For example, Sweden and Japan have achieved high waste recycling and waste-to-energy through detailed and specific waste classification rules, strict waste recycling regulations and extended waste producer responsibility systems (Mekonnen and Tokai, 2020; Malinauskaite *et al.*, 2017). For instance, in Japan, subsidies were provided for the construction of environmental facilities, public-private partnerships were encouraged in technology and innovations and end-users are engaged in the current monitoring of waste management programs and tracking the future emerging needs. Compared with developed countries, China's MSW recycling is still in its infancy. Facing the substantial growth of MSW generation, the Chinese government has set up eight pilot cities, including Beijing and Shanghai, to implement classification for the recycling of MSW. However, the results of the pilot project were not ideal (Lv *et al.*, 2020).

In the past four decades, Beijing has experienced substantial growth in MSW generation, growing from 1.04 million tons in 1978 to 10.11 million tons in 2019. The recycling and utilization rate is low in Beijing compared with other cities in developed countries (Chu *et al.*, 2019). According to China City Statistical Yearbook (2018), there are 27 existing waste treatment facilities in Beijing, representing an average daily treatment capacity of 24.3 thousand tons, including 10.1 thousand tons incinerated, 3.7 thousand tons treated with biochemicals and 10.5 thousand tons destined for a landfill. Nearly half of MSW in Beijing goes to landfills.

Hence, Beijing authorities urgently need to accelerate their MSW management. Multiple constraints from the government, residents, infrastructure, funds and supervision hinder MSW management. Wang and Geng (2012) and Ferronato *et al.* (2019) stated that deficient relevant regulations and government finances, as well as a lack of public participation, are the main barriers to MSW management. Similarly, the disorder in the informal recycling market and inconvenient recycling facilities are the dominant barriers to MSW management (Xiao *et al.*, 2018; Kumar and Dixit, 2018; Conke, 2018). Lack of regulations and supervision, ineffective management, insufficient funds and limited infrastructure are other barriers to effective solid waste management (Negash *et al.*, 2021; Bui *et al.*, 2022). In general, a large amount of literature has been accumulated on the barriers to the implementation of MSW management. Most previous studies focus on the status, characteristics and challenges of MSW management at the city and country levels in China, but none of these studies analyzes the barriers that hinder MSW management practices in Beijing. Facing multiple barriers, a research question is raised: "what are the dominant barriers to MSW management practices in Beijing?" The answers to this question can help Beijing Municipality improve its MSW management performance.

During the past decade, several researchers have tried to identify and analyze MSW management implementation barriers. Table 1 provides relevant information about these studies. As shown in Table 1, a variety of methods have been used in order to analyze the MSW barriers. Multi-criteria decision-making (MCDM) techniques, interpretive structural modelling (ISM) and statistical analysis are the most used methods for barrier analysis in the area of MSW. Some researchers also used a mixture of the above-mentioned methods.

Reference	Area	Method	Country/ region
Tseng (2009)	MSW management	ANP-DEMATEL	Manila
Dursun *et al.* (2011)	Health care waste management	Fuzzy MCDM	Istanbul
Dos Muchangos *et al.* (2015)	MSW management	ISM-DEMATEL	Maputo city
Mir *et al.* (2016)	MSW management	TOPSIS-VIKOR	Iran
Thakur and Anbanandam (2016)	Health care waste management	ISM-MICMAC	India
Yukalang *et al.* (2017)	MSW management	SWOT analysis	Thailand
Chauhan *et al.* (2018)	MSW management	ISM-DEMATEL	India
Coban *et al.* (2018)	MSW management	TOPSIS-PROMETHEE	Turkey
Kumar and Dixit (2018)	E-waste management	ISM-DEMATEL	India
Abdullah *et al.* (2019)	MSW management	Fuzzy DEMATEL	–
Fernando (2019)	MSW management	Statistical analysis	Sri Lanka
Sharma *et al.* (2020)	E-waste management	DEMATEL	India
Ayçin and Kayapinar Kaya (2021)	MSW management	Fuzzy DEMATEL	Turkey
Deus *et al.* (2022)	MSW management	Statistical analysis	Brazil
Thakur *et al.* (2022)	MSW management	Total-ISM	India
Current study	*MSW management*	*ISM-MMDE-MICMAC*	*Beijing*

Table 1.
Recent publications related to barrier analysis for MSW

DEMATEL and ISM are common methods for studying the complex problems of waste management and waste recovery. However, both DEMATEL and ISM depend on thresholds determined by experts in the calculation procedure and such subjective opinions will inevitably affect the results. Therefore, it is necessary to find a new approach to solve the complex relationship between multiple variables without subjectivity. The maximum mean de-entropy algorithm (MMDE) presented by Li and Tzeng (2009) is applied to obtain the appropriate threshold value. This algorithm provides a structured method to show the impact-relation plot between the barriers (Singh and Bhanot, 2020).

Based on the information provided in Table 1 and the above mentioned discussion, there is a lack of research in the area of MSW management in a megacity such as Beijing and the study tries to address the threshold issue of ISM to provide a structured hierarchy and framework of potential barriers. To address this gap, a hybrid DEMATEL-MMDE-ISM model is proposed in this research to analyze the barriers and the relationship between them and identify the key barriers affecting MSW management implementation. The main contributions of this study include the following:

(1) Identifies 12 barriers hindering the successful implementation of MSW management based on the literature and expert opinions.

(2) Combine the DEMATEL with the MMDE and ISM to form a hybrid approach and resolve the subjectivity issues of the traditional ISM approach.

(3) Develops a conceptual hierarchical model of the identified barriers, prioritizes the dominant barriers hindering MSW management practices in Beijing and provides policy suggestions according to the results.

The rest of the paper is structured as follows. Section 2 introduces the relevant literature in the waste management area to identify the barriers that impede the implementation of MSW management. Section 3 introduces the hybrid approach and explains the data acquisition process. Section 4 provides the results of the analysis and these are then discussed in Section 5. Section 6 introduces the theoretical and practical significance of this study and provides policy suggestions. Finally, Section 7 provides the main conclusions, limitations and future work.

2. Literature review

2.1 Barriers to MSW management in Beijing

There are barriers to MSW management that need to be addressed. However, prior research defining and analyzing MSW management implementation barriers are lacking. Therefore, this study conducts a rigorous literature review, identifying twelve barriers that were then classified into five categories. Table 2 presents the list of barriers identified from the literature, classified by barrier type and the publication in which they were identified. In the subsequent subsections, each barrier is described within the context of MSW management. Identifying this comprehensive list of barriers to MSW practices forms the first contribution of this study. Waste management in megacities has different characteristics compared to small cities/towns. There is a high level of complexity and uncertainty associated with handling the MSW in megacities like Beijing. In addition, existing traditional MSW approaches are often not designed to handle these complexities. Accordingly, the types of MSW implementation barriers in megacities like Beijing are different. In this study, the barriers were extracted from the related literature, which are defined in the context of Beijing.

2.1.1 Lack of policies and regulations (B1). Technically sound policies and regulations are the basis for successful MSW management. However, many developing countries lack adequate environmental policies and regulations for MSW management (Thakur *et al.*, 2022; Raj and Samuel, 2022; Batista *et al.*, 2021). China's current laws on the prevention and control of environmental pollution by managing solid waste pollution provide the legal foundation for MSW management, supplemented by other environmental regulations and local policies. However, there are no specific guidelines on solid waste classification, collection, transportation and recycling in these legal systems, which makes it difficult for MSW management executive departments to formulate specific solid waste classification management measures (Tai *et al.*, 2011; Li *et al.*, 2018). The above situation is not accidental and it is common in other developing countries as well. For instance, the MSW management plan proposed by Sao Paulo, Brazil, lacks specific implementation steps and definitions of relevant responsibilities (Polzer and Persson, 2016). Research on MSW management in Thailand's rapidly urbanizing areas also confirms the lack of relevant regulations and policies (Yukalang *et al.*, 2017).

2.1.2 Lack of government finances (B2). After a comprehensive analysis of the cases in developing countries, Guerrero *et al.* (2013) stated that government finances can drive improvement in the MSW management infrastructure; an increase in MSW collection, classification, transportation and treatment equipment; and special staff training to conduct MSW classification and treatment. However, in most developing countries there are schemes and strategies to provide funds and finances for establishing recycling facilities and infrastructure. For most developing countries, this results in a great economic burden (Troschinetz and Mihelcic, 2009; Raj and Samuel, 2022). The low efficiency of the MSW management system may come from the lack of government finances and participation. Such a barrier has been confirmed in Saudi Arabia, Pakistan and other developing countries as well as in Latin America (Al-Khatib *et al.*, 2015; Demirbas *et al.*, 2016; Hettiarachchi *et al.*, 2018).

2.1.3 Substantial growth of MSW generation (B3). Rapid urbanization and industrialization, as well as an increase in the urban population, immediately results in substantial growth in MSW generation, imposing great pressure on the MSW management system (Wang and Nie, 2001; Kumar *et al.*, 2017). This is especially true for developing countries and the high pressure created by the rapid growth in MSW generation leads to the

Barriers for MSW management	Code	References
Government-related		
Lack of policies and regulations	B1	Thakur *et al.* (2022), Raj and Samuel (2022), Batista *et al.* (2021), Ayçin and Kayapinar Kaya (2021), Wang and Jiang (2020), Li *et al.* (2018), Yukalang *et al.* (2017), Polzer and Persson (2016), Guerrero *et al.* (2013), Tai *et al.* (2011), Troschinetz and Mihelcic (2009), Hostovsky (2006), Troschinetz (2005)[1,2]
Lack of government finances	B2	Raj and Samuel (2022), Batista *et al.* (2021), Ayçin and Kayapinar Kaya (2021), Ferronato and Torretta (2019), Hettiarachchi *et al.* (2018), Demirbas *et al.* (2016), Al-Khatib *et al.* (2015), Guerrero *et al.* (2013), Troschinetz and Mihelcic (2009), Troschinetz (2005)[3]
Waste related		
Substantial growth of MSW generation	B3	Chen *et al.* (2020), Ferronato *et al.* (2019), Pan *et al.* (2019), Kumar *et al.* (2017), Troschinetz (2005), Wang and Nie (2001)[4]
Unclear composition of waste	B4	Raj and Samuel (2022), Han *et al.* (2019a), Dong *et al.* (2018), Han *et al.* (2018), Karthikeyan *et al.* (2018), Pan *et al.* (2015), Tai *et al.* (2011), Troschinetz and Mihelcic (2009), Troschinetz (2005), Buenrostro and Bocco (2003)[5]
Informal collection practices	B5	Ayçin and Kayapinar Kaya (2021), Fidelis *et al.* (2020), Darokar (2019), Mian *et al.* (2017), Wang *et al.* (2008), Zhuang *et al.* (2008), Hui *et al.* (2006)[6]
Low efficiency of waste management facilities	B6	Raj and Samuel (2022), Ayçin and Kayapinar Kaya (2021), Kumar *et al.* (2017), Lu *et al.* (2017), Habibi *et al.* (2017), Eiselt and Marianov (2015), Das and Bhattacharyya (2015)[7]
Knowledge dissemination related		
Lack of resident awareness	B7	Thakur *et al.* (2022), Raj and Samuel (2022), Ayçin and Kayapinar Kaya (2021), Wu *et al.* (2021), Zhou *et al.* (2019), Satapathy (2017), Demirbas *et al.* (2016), Guerrero *et al.* (2013), Troschinetz and Mihelcic (2009), Troschinetz (2005), Wang and Nie (2001)[8]
Insufficient publicity	B8	Ayçin and Kayapinar Kaya (2021), Lu and Sidortsov (2019), Yang *et al.* (2019), Zhou *et al.* (2019), Chen *et al.* (2017), Tai *et al.* (2011)[1,4]
MSW management process related		
Coordination failure in MSW management process	B9	Ayçin and Kayapinar Kaya (2021), Kituku *et al.* (2020), Zhou *et al.* (2019), Tai *et al.* (2011), Mohee (2002)
Lack of skilled employees	B10	Raj and Samuel (2022), Korai *et al.* (2020), Chauhan *et al.* (2018), Demirbas *et al.* (2016), Guerrero *et al.* (2013), Troschinetz and Mihelcic (2009), Troschinetz (2005), Wang and Nie (2001)[3]
Market related		
Under-developed waste recycling market	B11	Conke (2018), Xiao *et al.* (2018), Guerrero *et al.* (2013), Zhang *et al.* (2010), Troschinetz and Mihelcic (2009), Troschinetz (2005)[2]
Lack of government incentives	B12	Batista *et al.* (2021), Ayçin and Kayapinar Kaya (2021), Conke (2018), Xiao *et al.* (2018), Chen *et al.* (2010), World Bank (2005), Dong *et al.* (2001)[6]

Note(s): [1] https://www.orfonline.org/research/solid-waste-management-in-urban-india-imperatives-for-improvement-77129/#sdendnote23sym
[2] https://devpolicy.org/solid-waste-management-in-papua-new-guinea-20130812/
[3] https://www.worldbank.org/en/news/feature/2014/10/30/how-to-finance-solid-waste-management
[4] https://www.governancenow.com/views/columns/beyond-open-defecation-tackling-solid-waste-management-issues
[5] https://www.greenbiz.com/article/governments-and-companies-need-fill-plastic-data-gap
[6] https://www.earthisland.org/journal/index.php/magazine/entry/scrappy-endeavor/
[7] https://www.dailypioneer.com/2020/columnists/a-push-to-sort-out-the-urban-waste-crisis.html
[8] https://www.channelnewsasia.com/news/commentary/singapore-low-recycling-rates-reasons-why-14262732

Table 2.
List of barriers from the literature

poor operation of waste management systems (Troschinetz, 2005; Pan *et al.*, 2019; Chen *et al.*, 2020). In addition, the generation of MSW varies greatly between developing megacities and rural areas, as each requires an appropriate MSW management system. This matter needs the attention of policymakers and relevant industries (Ferronato *et al.*, 2019).

2.1.4 Unclear composition of waste (B4). A number of studies have shown that the unclear composition and physicochemical properties of waste streams reduces the efficiency of MSW classification and collection facilities. This may hinder sustainable MSW management and reduce the efficiency of waste-to-energy generation processes (Pan *et al.*, 2015; Dong *et al.*, 2018; Karthikeyan *et al.*, 2018). As many case studies for developing countries have shown, a better understanding of the characteristics of the waste streams generated in the region by municipal authorities is a prerequisite for the effective operation of MSW management systems (Han *et al.*, 2018, 2019a). However, many developing countries lack an accurate definition of indicators related to waste stream characteristics. This issue seriously reduces the operational efficiency of MSW management systems (Troschinetz and Mihelcic, 2009; Troschinetz, 2005; Buenrostro and Bocco, 2003). Furthermore, the high proportion of organic waste is the main feature that distinguishes China's MSW from western countries. However, the development of organic waste treatment technology and equipment in China is still in its infancy. Due to the high proportion of organic waste, MSW management in Beijing is facing severe challenges (Tai *et al.*, 2011).

2.1.5 Informal collection practices (B5). MSW collection in China includes formal and informal waste collection. The proportion of the informal collection is far higher than that of formal collection in some areas and more informal workers participate in the collection than formal workers (Han *et al.*, 2019a). Unfortunately, the management of informal collection is not effective and there is a lack of accurate statistics on the number of informal collection practitioners. Consequently, the total amount and composition of informally collected waste are relatively vague. It is difficult to regulate and implement an efficient and standardized waste treatment system given informal collection systems (Mian *et al.*, 2017; Wang *et al.*, 2008; Zhuang *et al.*, 2008). In addition, due to the lack of protective measures in informal waste collection, many informal collection practitioners may encounter health issues (Hui *et al.*, 2006; Wang *et al.*, 2008; Darokar, 2019; Fidelis *et al.*, 2020). It should be noted that informal collectors tend to focus on waste with high intrinsic recycling value, which harms MSW management of the other types of waste (Hui *et al.*, 2006).

2.1.6 Low efficiency of waste management facilities (B6). Many cities in China have widely distributed waste segregation/sorting facilities. However, due to poor awareness and social participation in MSW classification, many of these facilities have low efficiency (Lu *et al.*, 2017). As stated by Gao *et al.* (2020), the imbalanced spatial distribution of recycling facilities limits their service capacity. The facility location for MSW management needs to consider various factors, such as local residents' awareness, availability of waste transfer stations, waste treatment stations and waste vehicle routes (Yadav *et al.*, 2017). Moreover, more importantly, after households sort waste into different bins for recycling, it is then often absurdly mixed before being transported by sanitation departments (Das and Bhattacharyya, 2015). The lack of appropriate classified transportation for waste reduces the operational efficiency of waste management facilities. India's MSW management process faces the same challenges (Kumar *et al.*, 2017).

2.1.7 Lack of resident awareness (B7). Most previous studies have shown that public participation and willingness are important factors for the successful implementation of MSW management in developing countries. For example, Bhawal Mukherji *et al.* (2016) stated that environmentally relevant knowledge plays a crucial role in influencing habitual behaviors among residents in India. Zhou *et al.* (2019) found that households willing to engage in waste separation were positively correlated with efficient MSW management in Shanghai, China. Pakpour *et al.* (2014) pointed out that residents' attitudes toward recycling significantly influenced household waste behavior in Iran. However, most residents in developing countries are not aware of the benefits and responsibilities of waste recycling (Satapathy, 2017; Demirbas *et al.*, 2016; Han *et al.*, 2019b). In addition, it is important to invite residents to participate in the MSW policy-making stage, as Hostovsky (2006) pointed out that the lack of resident participation might lead to the Not In My Back Yard (NIMBY) syndrome.

2.1.8 Insufficient publicity (B8). Regarding MSW management, environmentally relevant knowledge includes both abstract and concrete knowledge and both play a crucial role in influencing residents' habitual behaviors (Bhawal Mukherji *et al.*, 2016). Abstract knowledge denotes a general awareness of MSW management, while concrete knowledge represents specific knowledge about local MSW management services (Schahn and Holzer, 1990). In developed countries, residents' habitual MSW management behaviors have been developed through 20–30 years of public campaigns. However, developing countries lack effective public campaigns and behavior-changing interventions. A case study on the implementation of a new MSW classification policy in Shanghai showed that the implementation of MSW sorting needs further publicity from the government (Zhou *et al.*, 2019; Lu and Sidortsov, 2019). A social survey in source-separated waste collection in Changsha also pointed out the importance of government and media publicity (Chen *et al.*, 2017). More publicity materials, advertisements and videos can be considered, together with stronger educational materials.

2.1.9 Coordination failure in MSW management processes (B9). MSW management is a systematic process: classification from the source and appropriate storage, collection, transportation and final treatment. This process requires the active participation of the legislative department of waste management, municipal authorities, waste management executive departments, front-line practitioners and residents. However, China thus far has not established an effective coordination mechanism and the above stakeholders have not been able to fully participate in MSW management (Tai *et al.*, 2011). One of the barriers to MSW recycling is the lack of cooperation among the various agencies in the MSW management system in terms of waste collection, separation, recycling, treatment, financing and management, as has been confirmed in previous studies on Shanghai, Kenya and Mauritius (Kituku *et al.*, 2020; Zhou *et al.*, 2019; Mohee, 2002).

2.1.10 Lack of skilled employees (B10). Advanced MSW management equipment and technologies require a trained workforce, which is currently lacking among Chinese employees (Wang and Nie, 2001). Many case studies have shown that most developing countries only invest a small amount of money in training personnel in MSW management facilities, creating a barrier to the successful implementation of MSW management systems (Troschinetz and Mihelcic, 2009; Troschinetz, 2005). This barrier to MSW management is also evidenced in other developing economies, such as Saudi Arabia, Pakistan and India (Demirbas *et al.*, 2016; Korai *et al.*, 2020; Chauhan *et al.*, 2018).

2.1.11 Underdeveloped waste recycling market (B11). Although the Chinese government has made great efforts to promote the recycling of MSW in recent years, there are still many issues in China's MSW recycling market. For example, waste classification standards are ambiguous (Xiao *et al.*, 2018). Due to the low price of recycled products and low recycling incentives from municipalities, there are few active participants in the recycling market (Zhang *et al.*, 2010). For many developing countries, the proportion of recyclable waste in the MSW stream, the expected scale and profitability of the waste market and the potential to establish a well-developed waste recycling market are important factors that influence waste management participants to decide whether to enter the waste recycling market (Troschinetz and Mihelcic, 2009; Troschinetz, 2005).

2.1.12 Lack of government incentives (B12). While *Lack of Government Finances* (B2) focuses on government financial support and funds for establishing infrastructures for MSW management, *Lack of Government Incentives* (B12) stresses on government incentives such as tax redemption and subsidies for the recycling activities. With the increasing government concern about MSW management, the potential of China's massive waste recycling market is gradually emerging. However, China's recycling market is still in its infancy and lacks the support of government policies, such as tax relief and subsidies for recycling industries. These types of incentives can motivate the private sector to enter the recycling market (Xiao *et al.*, 2018; Conke, 2018; Batista *et al.*, 2021). Chen *et al.* (2010) stated that the involvement of local governments in waste recycling boosts the development of the waste recycling industry. However, existing Chinese policies are more focused on high-value recyclable items, while there are no specific policies regarding low-value recyclable materials (Xiao *et al.*, 2018; World Bank, 2005).

2.2 Review of the related analytical methods

Table 3 tabulates the various methodologies employed by the articles which study the factors influencing waste management and recycling. It highlights the research area in which each approach is used and the researchers who employed it.

Among MCDM techniques, the decision-making trial and evaluation laboratory (DEMATEL) on barrier analysis has widely been used in the literature (Sharma *et al.*, 2020). DEMATEL is a mathematical calculation procedure proposed by Fontela and Gabus (1976), it focuses on the causal relationship between variables in complex problems. Through the calculation procedure of DEMATEL, the intensity with which each variable influences other variables and with which it is affected by other variables are calculated and output in the form of a graph or table. Based on the calculation results, the variables that are important to the problem can be determined. Therefore, DEMATEL can help identify the important barriers to the successful implementation of MSW management. As shown in Table 3, DEMATEL is widely used in waste management and waste recycling.

The ISM method has also been widely used for barrier analysis in the literature. The classic ISM was proposed by Warfield (1974) and is an effective method for studying the complex relationship between multiple variables. ISM can be used to visualize ambiguous dependencies and relationships among the influencing factors in the system in the form of a directed graph or matrix. A complex and ambiguous system can be transformed into a clear structural model by using graph theory (Bag and Anand, 2014; Mathiyazhagan *et al.*, 2013; Faisal, 2010). This structural model includes the direct and indirect relations of influence among the influencing factors and includes the overall influence of the factors on the system. These data are of great significance to the municipal authorities, who can use them to exert influence on the most influential barrier to MSW management in Beijing and promote successful MSW management implementation.

Method	Area of research	References
DEMATEL	Waste Management	Tseng (2009), Dos Muchangos *et al.* (2015), Kumar and Dixit (2018), Kumar and Dixit (2018), Abdullah *et al.* (2019), Sharma *et al.* (2020)
	Waste Recycling	Chauhan *et al.* (2018), Liu *et al.* (2020)
ISM	Waste Management	Ahmed and Panwar (2014), Thakur and Anbanandam (2016), Patidar *et al.* (2017), Kumar and Dixit (2018)
	Waste Recycling	Chauhan *et al.* (2018)
MICMAC	Waste Management	Dos Muchangos *et al.* (2015), Patidar *et al.* (2017), Kumar and Dixit (2018)
MCDM	Waste Management	Dursun *et al.* (2011), Mir *et al.* (2016), Coban *et al.* (2018), Shahnazari *et al.* (2020)
	Waste Recycling	Ilgin *et al.* (2015), Kumar and Dixit (2018), Rani *et al.* (2020)
MMDE	Empirical analysis	Li and Tzeng (2009), Lee and Lin (2013), Singh and Bhanot (2020)

Table 3.
Recent literature on influence factor analysis methodologies

Matrix-based multiplication applied to a classification (MICMAC) is usually used in combination with ISM analysis as a supplement. The purpose of MICMAC analysis is to derive the dependence and driving powers in the system of interconnected variables. It is quite effective when used with ISM to further develop interrelationships among elements, as it borrows results directly from the methodology (Bag and Anand, 2014). It involves aggregating the tabulated causal and dependent results from ISM and plotting them on a Cartesian coordinate plane. Variables can then be classified by the quadrants in which they are located. MICMAC produces clear results that are easily understood while requiring no additional input from experts.

DEMATEL and ISM are common methods for studying the complex problems of waste management and waste recovery. However, both DEMATEL and classical ISM depend on thresholds determined by experts in the calculation procedure and such subjective opinions will inevitably affect the results. Therefore, it is necessary to find a new approach to solve the complex relationship between multiple variables without subjectivity. The MMDE presented by Li and Tzeng (2009) is applied to obtain the appropriate threshold value. This algorithm provides a structured method to show the impact-relation plot between the barriers Singh and Bhanot (2020). Therefore, this paper proposes a hybrid DEMATEL-MMDE-ISM approach to resolve the subjectivity issues of the traditional ISM approach (Azadnia *et al.*, 2021; Ghadimi *et al.*, 2020) and it is presented in Subsection 3.1. This forms the second contribution of this research work.

3. Research methodology and data collection

3.1 A hybrid DEMATEL-MMDE-ISM approach

The ISM is an effective method for deriving output relationships among a set of variables. Using graph theory, a complicated model with loose and ambiguous relationships is transformed into a visually integrated structure model with multiple subsystems. The classic ISM approach determines the relationship between pairs of variables through expert discussion; it then filters the relationships that have less impact on the entire system through a subjective process. This study introduces a solution to this shortcoming of the classical ISM. It combines the characteristics of DEMATEL for data collection, the MMDE algorithm for threshold development and ISM for hierarchical model establishment. Combined with MICMAC, this hybrid method will provide an objective relationship analysis of the MSW management barriers. With the integration of the MMDE algorithm, a mathematical procedure based on entropy calculations is provided that will facilitate the integration of DEMATEL and ISM. Figure 1 depicts the steps for implementing this hybrid method. The steps of the proposed approach are presented here, while the details of each step are discussed in Appendix A1 due to space constraints.

3.1.1 Phase 1: Input data collection and analysis using DEMATEL.

Step 1: Obtain the relationship between barriers from experts.

Step 2: Build the average matrix A of experts' opinions.

Step 3: Normalize the initial direct relation matrix R.

Step 4: Calculate the total relation matrix T.

3.1.2 Phase 2: Threshold identification using MMDE.

Step 5: Obtain an appropriate threshold by MMDE.

3.1.3 Phase 3: Conceptual hierarchy model development and analysis for MSW management barriers using ISM-MICMAC.

Step 6: Construct the initial reachability matrix using the calculated threshold in Step 5.

Step 7: Establish the final reachability matrix.

Step 8: Determine level partitions.

Step 9: Develop a conceptual hierarchy model.

Step 10: Conduct MICMAC analysis.

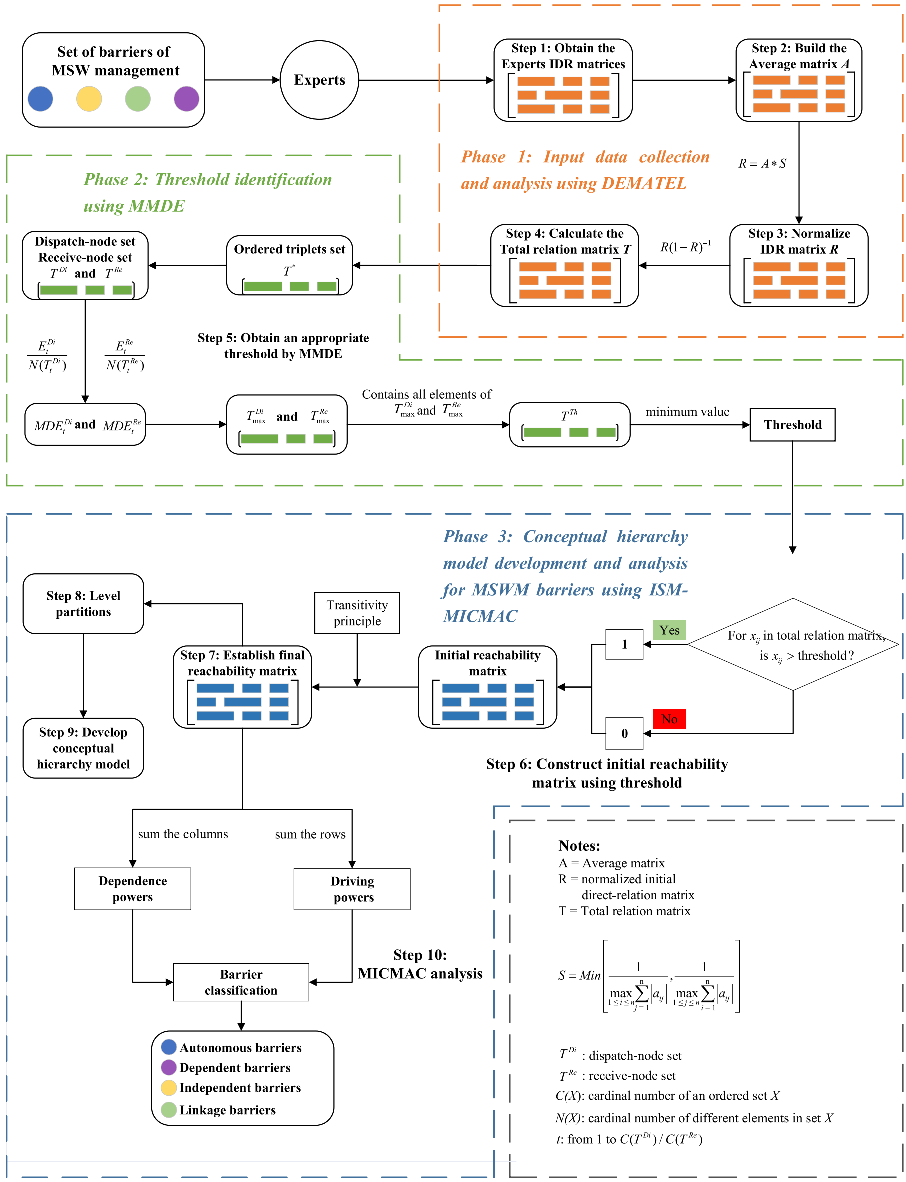

Figure 1.
Flowchart of the hybrid approach

3.2 Data acquisition

First, barriers affecting the successful implementation of MSW management in mega cities are identified through a literature review. A total of 12 barriers were identified and divided into five categories based on their role in MSW management: government, waste, knowledge dissemination, MSW management process and market (see Table 2). To implement the steps of the proposed methodology, a questionnaire survey was created to obtain expert opinions. See Appendix A2 for the expert questionnaire sample. In this study, a purposive sampling method is adopted. This means that the experts are selected based on their expertise in the area of MSW management. The experts must have at least 5 years of experience in the area of MSW management. In this research, a total of 25 experts participated in answering the questionnaire. Experts were required to only consider the directed relationship, not the overall relationship, between barriers. When experts input their opinions, they are required to fill in 0 or 1 only for the matrix of questionnaire answers, where 1 denotes that the expert believes barrier A impacts barrier B and 0 indicates that barrier A does not impact barrier B. In total, the opinions of twenty-five experts from waste management and recycling industries in Beijing were collected for the barriers.

4. Implementation and results

Based on the collected data (step 1 of the proposed methodology in Figure 1), the inputs have been used to implement the proposed hybrid methodology and to establish an interpretive structural model of barriers that affect the successful implementation of MSW management in Beijing. The structural model will help guide industry practitioners and government departments to promote MSW management in Beijing. The results are presented in the following subsections.

4.1 Results

As mentioned in subsection 3.2, twenty-five experts' opinions were collected and summarized to construct the initial direct relationship (IDR) matrix (see Table 4). Then, Cronbach's alpha (α), was used to validate the reliability of the survey results. Generally, a value of α higher than 0.7 indicates acceptable results. A low value of α (<0.70) indicates that the correlation between the barriers is poor and important barriers may be missed. The high value of α (>0.90) could mean barrier redundancy in Table 2. Table 4 shows that α is 0.85, which represents good reliability (Tavakol and Dennick, 2011).

The total relation matrix (TRM), shown in Table 5, is derived from the IDR matrix following the steps of Phase 1 of the methodology, as detailed in Appendix A1. The appropriate threshold value has been calculated using the MMDE method (Phase 2) with a value of 0.0038. MATLAB was utilized to program the MMDE algorithm and perform the calculations. It should be noted that the numbers marked with * in Table 5 are values greater than or equal to the threshold value; these will be filtered out and displayed as 1 in the initial reachability matrix (IRM) of the ISM (Phase 3).

The IRM in the classic ISM is transformed from the structural self-interaction matrix. In this study, the IRM was obtained from the TRM tabulated in Table 5. The TRM is converted into a binary matrix (i.e. 0 and 1) according to the calculated threshold value (0.0038) where 0 means that barrier A does not impact barrier B, while 1 indicates that barrier A does impact barrier B. Table 6 presents the constructed IRM.

Transitivity is applied in Table 6; in other words, if barrier A relates to B and B relates to C, then A also relates to C. Then, the final reachability matrix (FRM) is formed, as shown in Table 7. Modified elements are shown with 1*. It is worth mentioning that the driving power and dependence power required for MICMAC analysis are also calculated in Table 7.

Table 4.
Initial direct relationship matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0	5	6	5	17	3	6	11	19	10	19	17
B2	6	0	3	14	18	20	3	19	17	19	19	18
B3	1	2	0	11	14	15	1	0	14	0	0	0
B4	1	2	5	0	4	17	6	0	15	4	10	0
B5	2	3	5	13	0	5	4	1	8	12	15	6
B6	1	2	5	7	14	0	3	1	16	2	13	2
B7	2	1	5	15	15	16	0	3	9	0	4	1
B8	5	6	4	12	10	9	16	0	6	8	7	5
B9	3	2	3	6	17	16	2	1	0	4	14	6
B10	2	3	1	7	14	19	2	1	17	0	7	3
B11	1	3	4	5	8	15	5	2	9	10	0	3
B12	3	4	3	2	7	8	7	5	4	8	16	0
Total experts												25
Cronbach's Alpha												0.85

Note(s): B1: Lack of policies and regulations. B2: Lack of government finances. B3: Substantial growth of MSW generation. B4: Unclear composition of waste. B5: Informal collection practices. B6: Low efficiency of waste management facilities. B7: Lack of resident awareness. B8: Insufficient publicity. B9: Coordination failure in MSW management process. B10: Lack of skilled employees. B11: Under-developed waste recycling market. B12: Lack of government incentives

Based on the FRM, the reachability set and antecedent set for each barrier are identified. The reachability set consists of the barrier itself and the other barriers that it can reach, while the antecedent set consists of the barrier itself and the other barriers that can reach it. Subsequently, the intersection of these sets is derived for all barriers. After the identification of the top-level barrier, these barriers are separated from the remaining barriers. This iteration is continued until the levels of each variable are obtained and this procedure is repeated until all barriers are discarded. Table 8 shows the final partition of barriers in the FRM. B5, B6, B9 and B11 are located in level I, B3, B4, B10 and B12 are located in level II, B1 and B7 in level III, B8 in level IV and B2 are located in level V.

The MICMAC analysis process is as follows: the sum of each row and column of FRM is calculated, in which the sum of each row (Y-axis) is expressed as the driving power of the corresponding barrier and the sum of each column (X-axis) is expressed as the dependence power of the corresponding barrier. The results are presented in Table 7.

The barriers can be categorized into four clusters, i.e. autonomous, dependent, independent and linkage (Al Zaabi *et al.*, 2013; Shibin *et al.*, 2016). Figure 2 shows that the 12 identified barriers are grouped into three clusters and no barriers are categorized as linkage barriers. It is worth mentioning that even if B3, B4, B10 and B12 are classified as autonomous barriers, they have strong driving power, which is close to the level of independent barriers. This implies that the identified barriers are closely related.

4.2 Conceptual structural model

According to the last column in Table 8, barriers are assigned to different levels of the structural model. In Figure 3, the barriers located in level I are at the top of the hierarchy, while the barriers in level V are at the bottom. It is worth mentioning that, to comprehensively analyze the relationship between different barriers, the significant transitive links determined by experts are also shown in Figure 3.

Figure 3 shows the interpretive structural model of the barriers affecting Beijing's MSW management, which is the final output of the proposed hybrid approach. It should be noted

Table 5. The total relation matrix for the barrier set

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.0000	0.0013	0.0015	0.0012	0.0043*	0.0007	0.0015	0.0028	0.0048*	0.0025	0.0048*	0.0043*
B2	0.0015	0.0000	0.0007	0.0035	0.0045*	0.0050*	0.0007	0.0049*	0.0043*	0.0048*	0.0048*	0.0046*
B3	0.0002	0.0005	0.0000	0.0028	0.0036	0.0038*	0.0002	0.0000	0.0036	0.0000	−0.0001	0.0000
B4	0.0002	0.0005	0.0013	0.0000	0.0010	0.0043*	0.0015	0.0000	0.0038*	0.0010	0.0025	0.0000
B5	0.0005	0.0008	0.0013	0.0033	−0.0001	0.0012	0.0010	0.0002	0.0020	0.0031	0.0038*	0.0015
B6	0.0002	0.0005	0.0013	0.0018	0.0035	−0.0001	0.0008	0.0002	0.0041*	0.0005	0.0033	0.0005
B7	0.0005	0.0002	0.0013	0.0038*	0.0038*	0.0041*	0.0000	0.0008	0.0023	0.0000	0.0010	0.0002
B8	0.0013	0.0015	0.0010	0.0030	0.0025	0.0022	0.0041*	0.0000	0.0015	0.0020	0.0017	0.0013
B9	0.0008	0.0005	0.0007	0.0015	0.0043*	0.0041*	0.0005	0.0002	−0.0001	0.0010	0.0035	0.0015
B10	0.0005	0.0008	0.0002	0.0018	0.0035	0.0048*	0.0005	0.0002	0.0043*	0.0000	0.0017	0.0007
B11	0.0002	0.0008	0.0010	0.0012	0.0020	0.0038*	0.0013	0.0005	0.0023	0.0025	0.0000	0.0008
B12	0.0008	0.0010	0.0008	0.0005	0.0017	0.0020	0.0018	0.0013	0.0010	0.0020	0.0041*	0.0000
Threshold calculated by MMDE												0.0038

Note(s): B1: Lack of policies and regulations. B2: Lack of government finances. B3: Substantial growth of MSW generation. B4: Unclear composition of waste. B5: Informal collection practices. B6: Low efficiency of waste management facilities. B7: Lack of resident awareness. B8: Insufficient publicity. B9: Coordination failure in MSW management process. B10: Lack of skilled employees. B11: Under-developed waste recycling market. B12: Lack of government incentives

*Indicates that the value ≥ threshold value

	J											
I	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	1	0	0	0	1	0	0	0	1	0	1	0
B2	0	1	0	1	1	1	0	1	1	1	1	1
B3	0	0	1	0	0	0	0	0	0	0	0	0
B4	0	0	0	1	0	1	0	0	0	0	0	0
B5	0	0	0	0	1	0	0	0	0	0	0	0
B6	0	0	0	0	0	1	0	0	0	0	0	0
B7	0	0	0	0	0	0	1	0	0	0	0	0
B8	0	0	0	0	0	0	0	1	0	0	0	0
B9	0	0	0	0	0	1	0	0	1	0	0	0
B10	0	0	0	0	1	1	0	0	1	1	0	0
B11	0	0	0	0	0	1	0	0	0	0	1	0
B12	0	0	0	0	0	0	0	0	0	0	0	1

Note(s): B1: Lack of policies and regulations. B2: Lack of government finances. B3: Substantial growth of MSW generation. B4: Unclear composition of waste. B5: Informal collection practices. B6: Low efficiency of waste management facilities. B7: Lack of resident awareness. B8: Insufficient publicity. B9: Coordination failure in MSW management process. B10: Lack of skilled employees. B11: Under-developed waste recycling market. B12: Lack of government incentives

Table 6.
The initial reachability matrix for the barrier set

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	Driving powers
B1	1	0	0	0	1	1*	0	0	1	0	1	1*	6
B2	0	1	0	1	1	1	1*	1	1	1	1	1	10
B3	0	0	1	0	1*	1*	0	0	1*	0	1*	0	5
B4	0	0	0	1	1*	1	0	0	1*	0	1*	0	5
B5	0	0	0	0	1	1*	0	0	1*	0	1*	0	4
B6	0	0	0	0	1*	1	0	0	1*	0	1*	0	4
B7	0	0	0	1*	1*	1*	1	0	1*	0	1*	0	6
B8	0	0	0	1*	1*	1*	1*	1	1*	0	1*	0	7
B9	0	0	0	0	1*	1	0	0	1	0	1*	0	4
B10	0	0	0	0	1	1	0	0	1	1	1*	0	5
B11	0	0	0	0	1*	1	0	0	1*	0	1	0	4
B12	0	0	0	0	1*	1*	0	0	1*	0	1	1	5
Dependence Powers	1	1	1	4	12	12	3	2	12	2	12	3	

Note(s): B1: Lack of policies and regulations. B2: Lack of government finances. B3: Substantial growth of MSW generation. B4: Unclear composition of waste. B5: Informal collection practices. B6: Low efficiency of waste management facilities. B7: Lack of resident awareness. B8: Insufficient publicity. B9: Coordination failure in MSW management process. B10: Lack of skilled employees. B11: Under-developed waste recycling market. B12: Lack of government incentives

Table 7.
FRM of standard threshold barriers with MICMAC analysis

that although Figure 3 contains all the direct links and some significant transitive links, the interpretive structural model still contains some hidden links. For example, B2 impacts B8 and B8 impacts B7; hence, B2 indirectly impacts B7. Furthermore, the greater the driving power of barriers, the lower the level at which they are located in the structural model. Based on the driving force, all barriers are arranged from the bottom to the top of the structural model in ascending order by driving force.

Barriers	Reachability set	Antecedent set	Intersection set	Level
B5	5, 6, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 9, 11	1
B6	5, 6, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 9, 11	1
B9	5, 6, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 9, 11	1
B11	5, 6, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 9, 11	1
B3	3, 5, 6, 9, 11	3	3	2
B4	4, 5, 6, 9, 11	2, 4, 7, 8	4	2
B10	5, 6, 9, 10, 11	2, 10	10	2
B12	5, 6, 9, 11, 12	1, 2, 12	12	2
B1	1, 5, 6, 9, 11, 12	1	1	3
B7	4, 5, 6, 7, 9, 11	2, 7, 8	7	3
B8	4, 5, 6, 7, 8, 9, 11	2, 8	8	4
B2	2, 4, 5, 6, 7, 8, 9, 10, 11, 12	2	2	5

Note(s): B1: Lack of policies and regulations. B2: Lack of government finances. B3: Substantial growth of MSW generation. B4: Unclear composition of waste. B5: Informal collection practices. B6: Low efficiency of waste management facilities. B7: Lack of resident awareness. B8: Insufficient publicity. B9: Coordination failure in MSW management process. B10: Lack of skilled employees. B11: Under-developed waste recycling market. B12: Lack of government incentives

Table 8. Final partition of barrier set

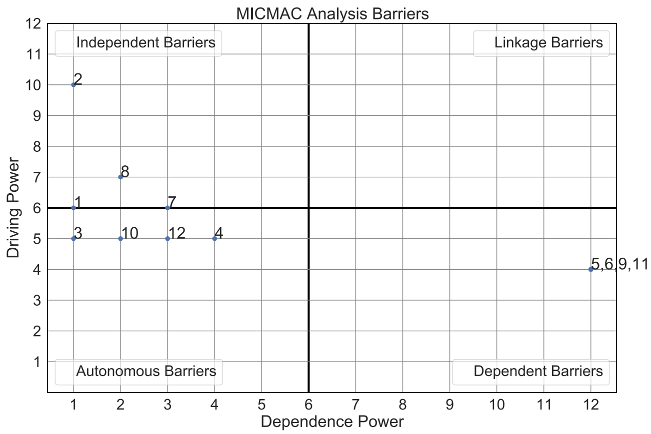

Figure 2. MICMAC analysis of barriers

5. Findings and discussion

This section explores the impacts of each barrier on MSW management in Beijing based on its classification in the MICMAC analysis (Figure 2) and its position in the structural model (Figure 3). It is worth noting that the relationship between the barriers is also the focus of this discussion. Generally, the barriers that rank higher in the structural model have more significant impacts on MSW management in Beijing. However, this does not mean that the lower ranked barriers have no impact on MSW management. Their impacts are more complicated and require a holistic analysis by transitive links.

5.1 Informal collection practices (B5)

B5 is located at level I and is identified as a dependent barrier, indicating that B5 is strongly influenced by other barriers. Therefore, B5 is regarded as a direct factor hindering MSW management practices in Beijing rather than as a strong influencer of other barriers. In other

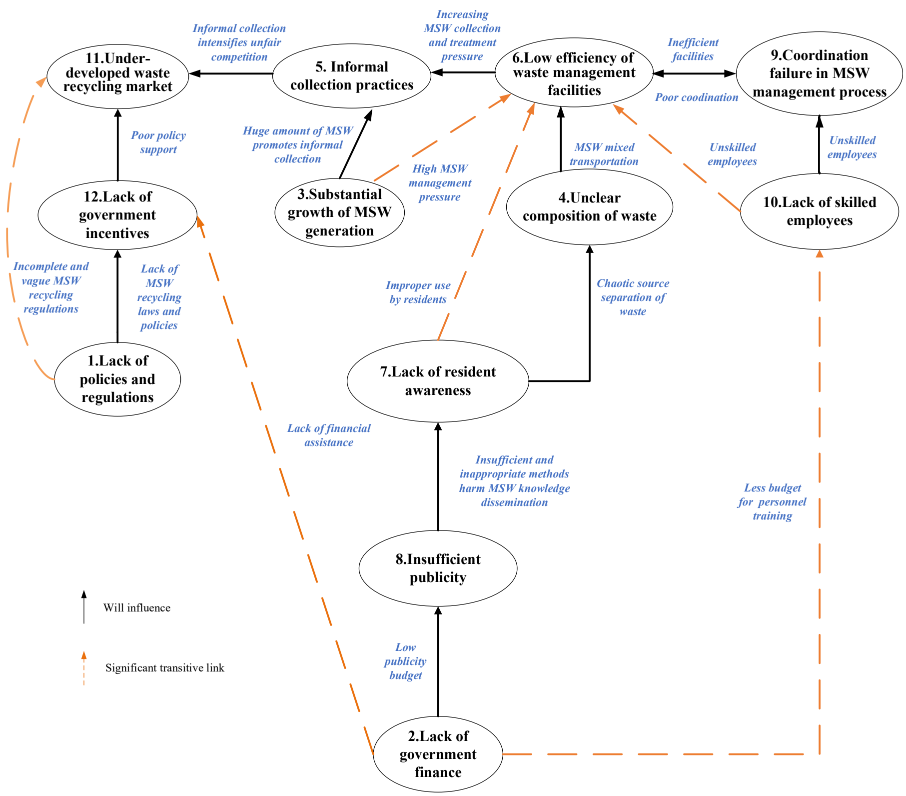

Figure 3.
Interpretive structural model of barriers

words, if only informal collection management was strengthened, it would not solve the fundamental difficulties in the successful implementation of MSW management practices faced by Beijing Municipality. In addition, as shown in Figure 3, the poor management of informal collection leads to an underdeveloped waste recycling market by promoting unfair competition practices.

5.2 Low efficiency of waste management facilities (B6)

B6 is also a dependent barrier influenced by other barriers. According to its position in Figure 3, B6 may not be a key barrier but only a direct factor hindering Beijing's MSW management. However, it is necessary to focus on the number and sites of recycling facilities. Waste management facilities are widespread in Beijing; however, their imbalanced and inefficient spatial distribution limits their service capacity (Gao *et al.*, 2020). In addition, Figure 3 shows that B6 influences B5, which means that low-efficiency waste management facilities increase the proportion of informal collection practices and reduce the operational efficiencies of the MSW management system in Beijing.

5.3 Coordination failure in MSW management process (B9)

B9 is also identified as a dependence barrier and is located at the top of the structural model. According to Figure 3, B9 and B6 interrelate. The coordination failure in the MSW management process reduces the efficiency of waste management facilities. Conversely, the low efficiency of waste facilities hinders the operational process involved in waste management and increases the risk of coordination failure. This finding is in line with the results of previous studies (Kituku *et al.*, 2020; Song *et al.*, 2021).

5.4 Underdeveloped waste recycling market (B11)

Similar to other barriers at level I of the structural model, B11 is also identified as a dependence barrier. Figure 3 shows that B11 is only affected by other barriers and has no direct impact on other barriers. It seems that B11 is simply a result of other barriers in the hierarchy, not a barrier recognized by the experts. A healthy waste recycling market aims to minimize waste and promote economic growth (Guerrero *et al.*, 2013). However, an underdeveloped waste recycling market is neither efficient nor viable, which impedes the ability to turn used materials into new ones (Exposito and Velasco, 2018).

5.5 Substantial growth in MSW generation (B3)

B3 is identified as an autonomous barrier and located at level II of the structural model. According to Figure 3, B3 is not affected by other barriers and it has two links influencing B5 and B6. The excessive growth in MSW quantities increase pressure on MSW collection and disposal and accelerate the development of informal collection practices, as has been confirmed in previous studies (Kumar *et al.*, 2017; Chen *et al.*, 2020). It should be noted that the substantial growth in MSW generation in Beijing is a fact and will not be affected by other barriers. However, considering the position of B3 in the hierarchy, it is also important to reduce waste generation, as this will facilitate MSW management in Beijing.

5.6 Unclear composition of waste (B4)

B4 is also identified as an autonomous barrier and located at the same level as B3 in the structural model. According to Figure 3, B4 only has a significant influence on B6. As stated by Dong *et al.* (2018) and Pan *et al.* (2015), unclear chemical composition and physical properties of waste streams have adverse effects on the sorting and segregation of MSW, which reduce the operational efficiency of waste management facilities and increase waste disposal costs. In addition, compared with industrialized countries, the percentage of organic household waste in China's MSW is relatively high, resulting in less efficient MSW management because of the immature technology for organic waste treatment and recovery (Tai *et al.*, 2011).

5.7 Lack of skilled employees (B10)

B10 is also classified as an autonomous barrier and ranked in level II. Recycling workers are poorly trained and lack the technical skills to operate and maintain recycling equipment. The structural model shows that B10 has two links, which serve as influence on B6 and B9. The shortage of skilled workers hinders cross-departmental collaboration and may bring coordination failure in MSW management; this finding is supported by previous studies (Troschinetz and Mihelcic, 2009; Troschinetz, 2005). Similarly, the lack of skilled employees leads to a reduction in the operational efficiency of MSW management facilities, which explains the link from B10 to B6 in the hierarchy. In addition, Chauhan *et al.* (2018) proposed that skilled labor shortages result in higher MSW management costs, which is not presented in Figure 3.

5.8 Lack of government incentives (B12)

B12 is also located at level II of the hierarchy and is identified as an autonomous barrier. The structural model shows that B12 only has a direct influence on B11. In other words, the absence of government support is detrimental to the development of the waste recycling market. Conversely, the positive impact of government-led initiatives on the rapid growth of the waste recycling market has been supported by a wide range of studies (Xiao *et al.*, 2018; Conke, 2018). Beijing's waste recycling market is still at an early stage of development and the government must provide incentives to promote the waste and recycling industry.

5.9 Lack of policies and regulations (B1)

B1 is ranked at level III and is classified as an independent barrier in Figure 3, which indicates that it plays an influencing role in the structural model. Policies and regulations are the foundation for a successful implementation of MSW management, as has been confirmed in many previous studies (Guerrero *et al.*, 2013; Li *et al.*, 2018; Polzer and Persson, 2016). The structural model shows that the absence of policies and regulations restrains government incentives in the MSW management system (Afroz *et al.*, 2017) and further impedes the growth of the formal waste recycling market. The influence of B1 on B11 is reflected through this path (B1→B12→B11). It should be noted that a healthy waste recycling market also needs regulatory and legal support, which is reflected by the transitive link from B1 to B11 in Figure 3.

5.10 Lack of resident awareness (B7)

B7, similar to B1, is ranked at level III in Figure 3. The link from B7 to B4 is straightforward. B4 can be considered as a linkage barrier based on its position in the structural model. The lack of residents' knowledge and willingness to sort waste will create an unclear composition and physicochemical properties of MSW at the waste generation source and reduce the separation efficiency of MSW, which is confirmed by Guerrero *et al.* (2013) and Zhou *et al.* (2019). It is worth noting that the transitive link between B7 and B6 indicates that residents' waste separation behavior may be one of the reasons for the inefficiency of waste sorting and treatment facilities. This transitive link is also perceived by Beijing Municipality, which has garbage classification instructors at 20,000 waste collection points. In addition, raising the awareness of residents about waste classification will enable enterprises to transform to become more environmentally friendly, which is conducive to the successful implementation of MSW management (Agamuthu *et al.*, 2009).

5.11 Insufficient publicity (B8)

B8 has the second strongest driving power in Figure 2, indicating that it is one of the main driving forces in the structural model and has a strong influence on other barriers. Agamuthu *et al.* (2009) and Zhou *et al.* (2019) pointed out that the government and public media should bear the main responsibility for disseminating environmental knowledge and delivering compelling messages to encourage citizen engagement. Similarly, a variety of existing studies support the link between B8 and B7 (Tai *et al.*, 2011; Troschinetz, 2005). In other words, if insufficient and inappropriate media is used to inform residents how to manage MSW classification and recycling, it will lead to the ineffective dissemination of waste sorting knowledge.

5.12 Lack of government finances (B2)

B2 has the strongest driving powers in Figure 2. It is located at level V in Table 8 and is recognized as the strongest barrier to MSW management in Beijing. The link from B2 to B8 is easily understood. A large number of case studies from developing countries show that government investment and financing play a key role in MSW management (Troschinetz and Mihelcic, 2009; Agamuthu *et al.*, 2009; Guerrero *et al.*, 2013). Lack of finances hinders the government's use of social media platforms to connect with citizens (David *et al.*, 2020). In addition, the significant transitive links from B2 to B10 and B12 highlight the importance of government finances to government incentives and the training of skilled employees.

6. Theoretical implications and policy suggestions

6.1 Theoretical implications

Most of the existing literature focuses on the status, characteristics and challenges of MSW management in Beijing and China (Chen *et al.*, 2020; Wang and Wang, 2013). However, few of them focus on barriers to MSW management. To fill this research gap, this study identifies the barriers hindering the successful implementation of MSW management in Beijing and constructs a structural model of such barriers, thereby laying a foundation for further analysis of the barriers faced across the Beijing-Tianjin-Hebei region and throughout China's MSW management.

Now that a documented approach to analyzing barriers to MSW management has been proposed, the government and the participants in the waste recycling industry have an effective framework to guide the management and recycling of MSW and how to effectively reduce participation risks in the waste recycling market. The top three MSW barriers are identified: lack of government finances (B2), insufficient publicity (B8) and lack of policies and regulations (B1). The appropriate budgetary allocation and monitoring through government finance is the premise for the successful implementation of MSW management. Adequate budget allocation for employee skills training can also further increase the number of employees skilled in MSW management. Residents participating in MSW source separation are required to have corresponding waste classification knowledge and willingness, which requires more effort by the government and public media to popularize and publicize knowledge. More detailed regulations related to waste classification and recycling are also needed for the successful implementation of MSW management. Moreover, although the underdeveloped waste recycling market hinders MSW management, this hindrance seems to be a result of other barriers in the structural model rather than a barrier to MSW management practices recognized by experts.

6.2 Policy suggestions

To provide policy suggestions, the discussion in this subsection is based on the results in Section 5 and the opinions of experts, as well as the MSW management status in Beijing.

6.2.1 Legislation.

(1) Waste source separation is the premise to ensure effective MSW recycling. Beijing Municipality is encouraged to promote more detailed legislation on waste classification in the first place. Beijing could learn from the success of Shanghai, which has had remarkable progress in its trash-sorting campaign since its garbage classification regulations went into effect on July 1, 2019 (Zhou *et al.*, 2019).

(2) Establish an extended responsibility system for waste producers and subdivide the responsibility for waste classification to individual producers like many European countries (Leal Filho *et al.*, 2019).

(3) Review objectives and practices of Extended Producer Responsibility (EPR) schemes for capitalizing on circularity potential.

(4) In March 2020, the European Commission adopted the new Circular Economy action plan (CEAP), as one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The EU's new circular action plan paves the way for a cleaner and more competitive Europe. Similar action plans and policies can be developed for China and implemented in megacities like Beijing.

(5) The Beijing local government needs to make waste management plans in relation to nonhazardous waste. As a result, certain obligations need to be imposed on local authorities to ensure that a service is provided for collection of household waste and to provide facilities for the recovery and disposal of such waste.

6.2.2 Economic support.

(1) Municipalities should pay more attention to budgetary allocation and monitoring to ensure that waste management departments and communities can obtain adequate financial assistance.

(2) Encourage the development of waste recycling and treatment technologies and accelerate the process of technology localization by setting up special funds.

6.2.3 Criterion formulation.

(1) A unified and clear standard should be established to define the composition and physicochemical properties of MSW to formulate the optimal sorting and recycling strategy.

(2) A volume-based waste fee system can be adopted to encourage residents to reduce the amount of waste produced, thus reducing the pressure of the MSW management system (Park and Lah, 2015).

6.2.4 Supportive policy.

(1) Given the substantial growth in MSW generation, some measures (such as tax incentives and subsidies for environmentally friendly companies) can be adopted by the government to encourage the development of green enterprises.

(2) The government should give more policy support to the waste recycling market, such as tax incentives for enterprises involved in the waste recycling industry.

(3) Substantial penalties can be considered for offences including fines, imprisonment and/or liability for clean-up measures.

(4) Develop and amend legislation to end-of-waste and by-products to remove barriers to circular economy developments.

6.2.5 Resident education.

(1) Various measures (such as dissemination of MSW classification and recycling information on community bulletin boards, MSW classification videos on social media and traditional media, displaying MSW classification information on garbage cans and trucks) can be implemented by the government and public media to improve residents' knowledge level and willingness to classify MSW.

(2) Integrating waste classification and recycling knowledge into school education is proposed; this integration includes waste management curriculum and regular voluntary activities, so as to nourish students' attitude and knowledge as well as willingness to participate in MSW recycling.

(3) After the residents' willingness to participate in the waste classification has been significantly improved, a more granular level of MSW classification can be adopted. For example, recyclable waste could be sorted into five categories, namely, paper, glass products, waste metal, plastic packaging, daily waste plastics (Wen *et al.*, 2014).

(4) Raise awareness amongst policy makers and elected representatives as to how circular economy developments can support regional development and jobs.

(5) As part of the education and awareness program, local and federal governments can develop a communications strategy around promoting the meaning and potential of a transition to a circular economy by establishing proper MSW management systems.

6.2.6 Facility monitoring.

(1) The use of waste management facilities should be monitored by the community or waste management department in the region. If necessary, fines and other penalties can be taken to restrict improper use by residents.

6.2.7 Staff training.

(1) Municipal authorities should pay more attention to staff training and some measures (such as adequate budgetary allocation for employee skill training and a higher salary for employees) can be taken to increase the number of skilled employees in MSW management.

7. Concluding remarks, limitations and future works

The main objective of this study is to answer the question "What are the main barriers hindering the successful implementation of MSW management in Beijing?" by proposing a conceptual structural model of the interrelations of various barriers identified from the related literature. The hybrid DEMATEL-MMDE-ISM model is used in conjunction with experts' opinions and insights to propose this conceptual structural model.

The relationship between the barriers that affect the successful implementation of MSW management in Beijing was analyzed and discussed based on the conceptual structural model. As shown in this research, a lack of economic support from the government, imperfect MSW-related laws and regulations, the low education of residents and the lack of publicity of waste recycling knowledge are the main barriers to MSW management in Beijing. This research lays a solid foundation for research in this field in China. Combined with expert opinions, the paper provides suggestions and guidance to municipal authorities and industry practitioners to help the successful implementation of MSW management. Effective policy suggestions are promoting legislation for waste source classification and recycling, formulating clear waste classification and recycling standards and implementing them accurately, supervising and training on the use of waste classification and recycling facilities, improving the efficiency of waste management knowledge dissemination and increasing residents' willingness to participate in waste classification.

Like all studies, this study also has some limitations. First, most of the literature reviews on which these findings are based are related to developing countries. Barriers to MSW management vary on a regional basis; therefore, some factors may be local to Beijing and neglected in this work. Second, it is necessary to consider more expert opinions to minimize the estimation error caused by the small sample size. This issue has been addressed using the MMDE extension of the proposed hybrid method. As a future work direction, although Beijing is a developing city, its urban scale and development environment are similar to those of representative cities in developed countries such as New York, USA; Tokyo, Japan. Therefore, comparative studies with developed cities could provide further insights and more practical recommendations. Furthermore, given the time and availability of experts, gathering more results from the survey opens up the possibility for a robust statistical analysis of the results using structural equation modelling (SEM), given that a research hypothesis has been established. This would ideally provide a comprehensive factor and path analysis along with simultaneous equation models to estimate causal relationships for the hierarchy model.

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Appendix 1

The hybrid DEMATEL-MMDE-ISM approach

Figure A1 shows the steps for implementing the proposed hybrid ISM method based on the identified barriers.

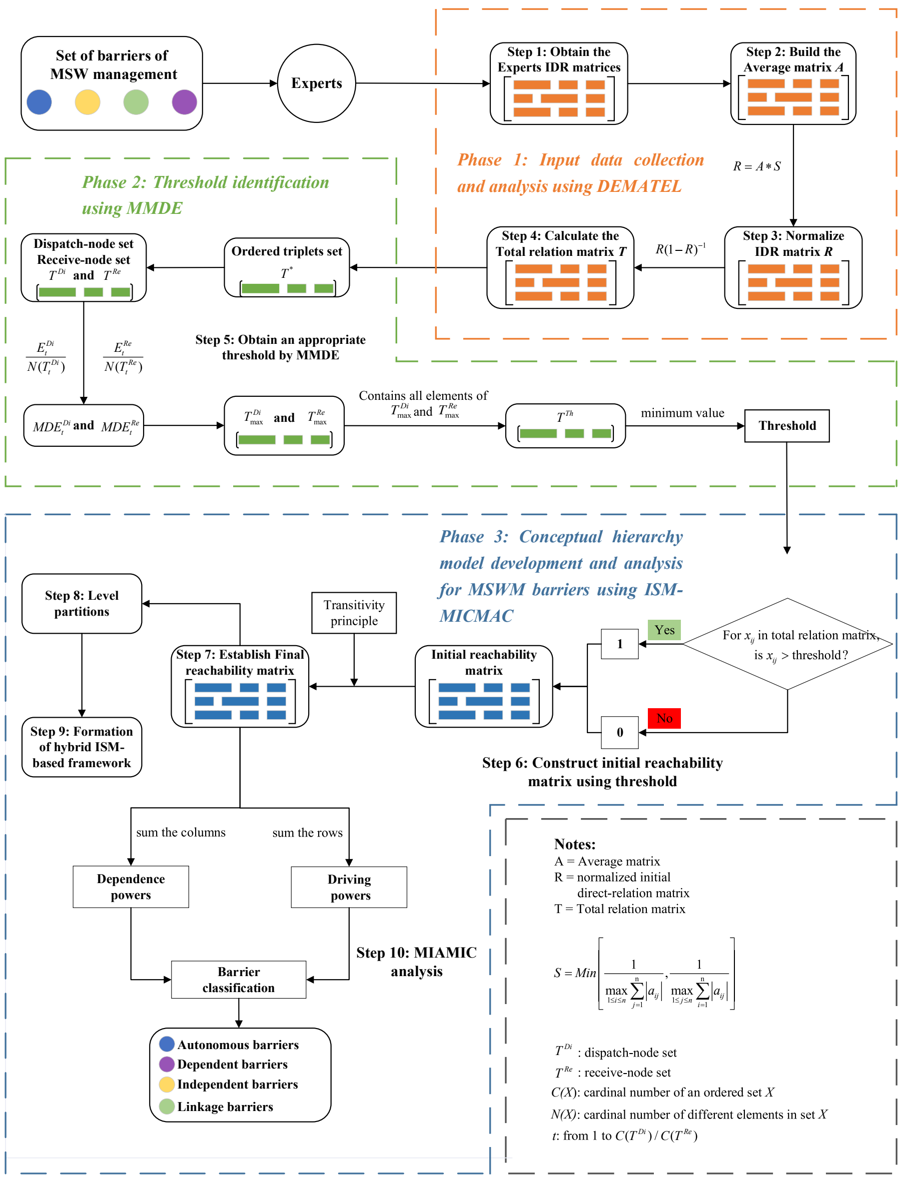

Figure A1.
Flowchart of the hybrid DEMATEL-MMDE-ISM method

Phase 1: Input data collection and analysis using DEMATEL

Step 1: Obtain the relationship between the barriers from the experts

This study built a questionnaire to obtain expert opinions on the barriers influencing MSW management in Beijing. When experts fill in the questionnaire, they are required to only consider the direct relationship between barriers, not the overall relationship between barriers in the system. This step is to make it more convenient to fill in the questionnaire and obtain more data for calculation and analysis. Each expert is asked to fill the comparison matrix using a binary number, such as (0, 1), among the barriers, as shown in Table A1. The binary number 1 denotes that the expert believes barrier A impacts barrier B. The binary number 0 indicates that barrier A does not affect barrier B.

Step 2: Build the average matrix A of experts' opinions

Assume that there are n barriers and h experts. Each expert k ($1 \le k \le h$) is asked to give an opinion on the degree to which barrier i influences barrier j related to MSW management in Beijing. The degree is indicated as x_{ij}^k, ranging between 0 and 1. If x_{ij}^k is 1, it indicates that the kth expert believes barrier i impacts barrier j. If x_{ij}^k is 0, it indicates that barrier i does not affect barrier j. According to experts' opinions on the n barriers, a n × n matrix $X^k = [x_{ij}^k]_{n\times n}$ can be obtained. In addition, x_{ij}^k is set as 0 if $i = j$, which means that barrier i has no influence on itself. Then, the average matrix A of experts' opinions is calculated by

$$\mathbf{A} = [a_{ij}]_{n\times n} = \frac{1}{h}\sum_{k=1}^{h}\left[x_{ij}^k\right]_{n\times n} \tag{A-1}$$

where matrix A is known as the initial direct relation (IDR) matrix and a_{ij} is the element of matrix A.

Step 3: Normalize the IDR matrix

The normalized IDR matrix R can be obtained in the following equations:

$$s = Min\left\{\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n} a_{ij}}\right\} \tag{A-2}$$

$$\mathbf{R} = \mathbf{A} \times s$$

All elements in the matrix R comply with $0 \le r_{ij} < 1$, $0 \le \sum_{j=1}^{n} r_{ij} \le 1$ and at least one i such that $\sum_{j=1}^{n} r_{ij} \le s$.

Step 4: Calculate the total relation matrix T

After obtaining the matrix R, the total relation matrix T can be obtained by summing the direct effects and all the indirect effects.

$$\begin{aligned}\mathbf{T} &= \sum_{i=1}^{\infty} R^i = R + R^2 + R^3 + \ldots + R^m = R\left(I + R + R^2 + R^3 + \ldots + R^{m-1}\right)\\ &= R(I-R)^{-1}(I - R^m)\\ &= R(I-R)^{-1}\end{aligned} \tag{A-3}$$

where I is the identity matrix and R^m denotes an m-indirect effect. Note that $\lim\limits_{m\to\infty} R^m = [0]_{n\times n}$ and $[0]_{n\times n}$ is a n × n null matrix.

Barriers	B1	B2	…	Bn-1	Bn
B1	0				
B2		0			
…			0		
Bn-1				0	
Bn					0

Table A1. Results of barriers hindering MSW management in Beijing

Phase 2: Threshold identification using MMDE

Step 5: Obtain an appropriate threshold by MMDE

In this study, the MMDE algorithm is applied to obtain an appropriate threshold value for delineating the impact-relations map.

Step 5.1: The matrix T is converted into an ordered set T, $(t_{11}, t_{12}, t_{21}, t_{22}, \ldots, t_{nn})$. Then, the elements in set T are arranged in descending order to obtain the ordered triplets T^* in the form of (t_{ij}, x_i, x_j).

Step 5.2: The second element in the ordered triplets T^* is extracted to form a set of ordered dispatch nodes, which is denoted as T^{Di}.

Step 5.3: The first t elements of T^{Di} are taken out as new set T_t^{Di} and the probabilities of different elements in the set are assigned. Then, the de-entropy E_t^{Di} of the set T_t^{Di} is calculated. Thus, the mean de-entropy (MDE) value can be obtained by

$$MDE_t^{\mathrm{Re}} = \frac{E_t^{Di}}{N\left(T_t^{Di}\right)} \tag{A-4}$$

Set the initial value of t as 1 and then the value of t is determined by raising the value from 1 to $C(T^{\mathrm{Di}})$ in increments of 1.

Step 5.4: For the generated MDE values in Eq. (A-4), the maximum MDE value is picked and is designated as $T_{\max}^{Di}$.

Step 5.5: The third element in the ordered triplets T^* is taken to form a set of ordered receive nodes T^{Re}. Similar to step 5.3 and step 5.4, a maximum MDE receive-node $T_{\max}^{Re}$ can be derived.

Step 5.6: Take the first u elements in the set T^* as a subset T^{Th}, including all elements of $T_{\max}^{Di}$ and $T_{\max}^{re}$. The threshold value is calculated based on the minimum influence in T^{Th},

$$1 < C\left(T^{th}\right) < C(T^*) \tag{A-5}$$

Phase 3: Conceptual hierarchy model development and analysis for MSW management barriers using ISM-MICMAC

Step 6: Construct the initial reachability matrix using the threshold

According to the matrix T in Step 4, combined with the appropriate threshold value obtained in Step 5, the initial reachability matrix (IRM) can be constructed.

$$t_{ij} = \begin{cases} 1, \ t_{ij} \geq \text{threshold} \\ 0, \ t_{ij} < \text{threshold} \end{cases} \tag{A-6}$$

where t_{ij} is the element in the matrix T. It should be noted that according to the definition of the IRM, when the total relation matrix is converted to the IRM, the elements on its diagonal are all converted to 1.

Step 7: Establishment of the final reachability matrix

The transitivity principle is applied to the IRM to find the final reachability matrix (FRM); see Table A2. In the transitivity principle, if barrier A relates to barrier B and barrier B relates to barrier C, then barrier A relates to barrier C. In the FRM, 1 means that there is an important relationship between barrier A and barrier B, while 0 indicates that the relationship between barrier A and barrier B is not important in the overall structure.

In this FRM, the summation of each row and column is worked out. The summation of the rowwise is the driving power of the corresponding barrier, which it may help achieve. The summation of column wise is the dependence power of the corresponding barrier, which may help in achieving it. The driving power and dependence power will be applied in the MICMAC analysis, which is presented in Step 10.

Step 8: Level partitions

The FRM is partitioned into different levels based on the three sets: the reachability set, the antecedent set and the intersection set, as shown in Table A3. There are five columns in this table. The first and last columns represent the barriers and level, respectively. The reachability set for a barrier includes the barrier itself and the other barriers that can be reached. The antecedent set contains the barriers themselves and the other barriers that can be reached. Subsequently, the intersection set for each barrier is the intersection of the corresponding reachability and antecedent sets.

Once these three sets are obtained, the barriers for which the reachability and intersection set are the same are assigned as level I. After the first iteration, the barriers are assigned as level I. This process is repeated until each barrier has been determined.

Step 9: Conceptual hierarchy model

In this step, a digraph is developed representing the direct relationships and hierarchical levels of barriers. Based on Table A3, the hierarchical structure is constructed. The first and last levels are illustrated at the top and bottom of this framework digraph, respectively. At each level, the barriers are connected to barriers based on the relationships obtained in Table A2.

Step 10: MIAMIC analysis

Based on the driving power and dependence power in Table A2, all barriers are grouped into four categories: independent barriers, linkage barriers, autonomous barriers and dependent barriers. See Figure A2.

(1) Independent barriers: They have strong driving power but weak dependence power. They are often critical factors affecting other barriers and they play a major driving role hindering MSM management in Beijing.

(2) Linkage barriers: They have strong driving power and dependence power. They are closely related to other barriers in the system and they can exert a certain influence on the system, but they are also restricted by many barriers in the system.

Barriers	B1	B2	. . .	Bn-1	Bn	Driving power
B1	1					
B2		1				
. . .			1			
Bn-1				1		
Bn					1	
Dependence power						

Table A2. Final reachability matrix

Barriers	Reachability set	Antecedent set	Intersection set	Level
B1				
B2				
. . .				
Bn-1				
Bn				

Table A3. Final level of each barrier

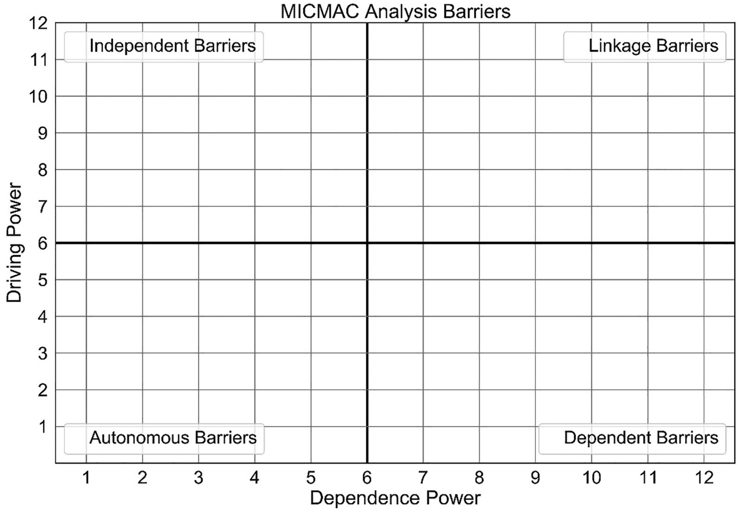

Figure A2. Driving and dependence power diagram for the barriers

(3) Autonomous barriers: The barriers have weak driving power and dependence power. These barriers are relatively disconnected from the system.

(4) Dependent barriers: The barriers have weak driving power but strong dependence power. These barriers are often influenced by other barriers and they play a small role in hindering MSM management in Beijing.

Appendix 2

Expert Questionnaire

Dear experts:

We would like to thank you for your valuable time to fill out the questionnaire! To determine the current problems of municipal solid waste (MSW) management and recovery in Beijing and to sort out the barriers affecting the implementation of MSW management in Beijing, please give your judgment on the logical influence between the barriers. THank you again for your cooperation and help!

A2-1. Questionnaire description

In this study, 12 barriers affecting municipal solid waste management in Beijing were identified (Table A4). This questionnaire lists the relationship between all the barriers. Please fill your judgment in Table A5 according to your professional knowledge.

A2-2. Questionnaire filling instructions

The results you fill in reflect the logical relationship between indicators and the degree of mutual influence. For details, see the following example: where B represents the indicator of influence element, B_{ij} means the value in the table represents the direct influence degree of B_i on B_j and $B_{ij} \in [0, 1]$. Generally, $B_{ij} \neq B_{ji}$ and the direct influence matrix formed by scoring is not a symmetric matrix. If $B_{ij} = 0$, then B_i has no direct effect on B_j. If $B_{ij} = 1$, then B_i has a direct effect on B_j.

A2-3. Questionnaire

Symbol	Primary barriers	Secondary barriers	Description
B1	Government	Lack of policies and regulations	Lack of laws, policies and incentive plans related to waste recycling, or the enforcement of laws and regulations is not in place. The current regulations of Beijing Municipality on the management of domestic waste introduce the collection and transportation of waste vaguely
B2		Lack of government finances	Government finances are the support for improving the MSW management infrastructure, the increase of MSW collection, classification, transportation and treatment equipment and the special training for MSW classification and treatment staff. However, in most developing countries, there is no appropriate waste disposal fee or tax based on the amount of waste, so the above expenses can only be borne by the government. For most developing countries, this has caused a great economic burden
B3	Waste	Substantial growth of MSW generation	With the rapid development of urbanization and industrialization, the rapid increase of urban population, the following side effect is the substantial growth of MSW generation, which has caused great pressure on the MSW management system
B4		Unclear composition of waste	Unclear composition of chemical and physical properties of waste stream reduces the recovery efficiency and increases the recovery cost. Compared to the developed countries, food waste accounts for a large proportion of China's MSW and the recycling technology of food waste is not perfect, so it is difficult to effectively recycle
B5		Informal collection practices	China's overall MSW collection includes both formal and informal waste collection. Unfortunately, the management of informal collection is not effective, whereby there is a lack of accurate statistics on the number of informal collection partitioners and the total amount and composition of informal collection waste are relatively vague. The informal collection systems make it more difficult to regulate and implement an efficient and standardized waste treatment system
B6		Low efficiency of waste management facilities	Due to the weak knowledge level or willingness of residents in MSW classification, human destruction and other reasons, the efficiency of many waste segregation/sorting facilities is low

(*continued*)

Table A4. Description of barriers to MSW management in Beijing

Symbol	Primary barriers	Secondary barriers	Description
B7	Knowledge dissemination	Lack of resident awareness	Citizens' understanding includes MSW related knowledge, such as the relationship between MSW recycling and environment, waste classification and recycling knowledge and residents' willingness to actively participate in MSW classification and care about environmental issues. Unfortunately, most residents are not aware of the benefits of waste recycling and their responsibilities in waste recycling in China
B8		Insufficient publicity	The publicity mode is relatively single, the publicity effect is insufficient and the scope of knowledge dissemination is not wide enough
B9	MSW management process	Coordination failure in MSW management	MSW management is a systematic project involving many aspects and it requires the active participation of waste management legislative departments, municipal authorities, waste management implementation departments, front-line practitioners and residents. However, at present, China has not established an effective coordination mechanism and the above units have not fully participated in the management of municipal solid waste
B10		Lack of skilled employees	The general education level of China's MSW practitioners is relatively low. At present, more advanced and efficient MSW management equipment and technology need to have a high level of technology, which puts forward higher requirements for personnel training and brings greater economic pressure on the municipal authorities
B11	Market	Underdeveloped waste recycling market	Although the Chinese government has done a lot of work in promoting the recycling of municipal solid waste in recent years, there are still many deficiencies in China's MSW recycling market due to its late start, which need to be improved
B12		Lack of governmental incentives	China's waste recycling market is still in its infancy, lacking the support of government policies, such as tax relief and subsidies for corresponding industries. Private enterprises and investors have great risks in entering the market, which hinders the enthusiasm of investors and the development of the industry to a certain extent Local governments regard waste recycling as a public service rather than an industry that can bring profits to enterprises, then the traditional way of thinking of local governments may increase the systemic risk of the waste recycling market and hinder investors from entering the waste recovery market

Table A4.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0											
B2		0										
B3			0									
B4				0								
B5					0							
B6						0						
B7							0					
B8								0				
B9									0			
B10										0		
B11											0	
B12												0

Table A5. Results of barriers hindering MSW management in Beijing

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