

Towards the circular economy: Analysis of barriers to implementation of Turkey's zero waste management using the fuzzy DEMATEL method

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Abstract

Zero waste has an important position in the circular economy model in terms of manufacturing recyclable products instead of products to be consumed quickly, reducing the amount of waste, developing and implementing recycling/reuse technologies, and thus ensuring resource efficiency. A zero-waste strategy is one of the basic steps to achieve the goal of the circular economy. The number of studies conducted on Turkey's zero waste management strategies referring to the circular economy is quite limited. To fill this gap in the literature, this study aims to identify the potential barriers which have an important role in zero waste management practices in Turkey. Through a broad literature review and expert opinions, 12 key barriers for zero waste implementation in Turkey have been defined in view of circular economy principles. Then, fuzzy DEMATEL methodology is employed to examine which is the most influential barrier affecting zero waste management success and to identify the interdependence of these barriers. The results indicate that uncertainty of the goals and tactics relevant to the circular economy and lack of financial and economic aid are key causal barriers that affect Turkey's zero waste management.

Keywords

Circular economy, barriers, waste, zero waste, fuzzy logic, DEMATEL

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Introduction

The circular economy approach is a new production–consumption model developed as an alternative for the linear economic model based on the classic ‘produce, use, dispose of’ method (World Economic Forum, 2020). The circular economy model aims at reducing consumption of natural resources and making economic profits from them by giving importance to designing products in a reusable form and recycling and zero waste implementations. UNEP (2006) emphasizes that the circular economy model balances economic development with environmental and resource protection. The circular economy (CE) model targets mitigation of the adverse effects of environmental degradation by promoting the 3R's – recycle reuse and reduce – policies and programmes applied at every stage of production and consumption processes (Ghisellini et al., 2016; Singh et al., 2020; Yang et al., 2014). Hence, the aim is to reduce the amount of waste in all the processes from production to consumption and to maintain economic growth by preserving natural resources (Yang et al., 2014). In the CE model, wastes are regarded as a resource, and the recovery and recycling of wastes are primarily taken into consideration (minimizing the cost of raw materials, maximizing resource efficiency and environmental benefit). Within the scope of the CE, waste management has become a prominent issue,

especially for municipalities, public institutions, managers and researchers. However, implementation studies on this matter are quite new and inadequate (Haupt et al., 2017; Malinauskaite et al., 2017; Zhang et al., 2019). In 2015, the European Commission adopted the Circular Economy Package, which includes legislative regulation proposals and a comprehensive action plan on wastes. In order to speed up economic growth and prevent environmental disasters, it is foreseen that taking precautions such as adopting the eco-design principle in product design, reducing and recycling the wastes and reducing greenhouse gas emissions into the atmosphere is required within the zero-waste programme (Veral and Yiğitbaşıoğlu, 2018). It is also predicted that great value will be added to the CE by reducing the raw material cost and ensuring more efficient use of limited resources with the zero waste strategy (EASAC Circular Economy, 2015).

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One of the main targets of the CE is to realize zero waste management effectively. Therefore, zero waste plays a significant role in the CE in that it provides economic value by saving materials, reselling waste, utilizing waste in other materials and avoiding environmental damage (Nizar et al., 2019). Recycling and recovery of waste is a precondition for a circular economy. Resources and materials can be recycled, returned to the economy and reused, which will reduce the production costs and create more jobs and connections (Deselnicu et al., 2018).

With the emergence of the circular economy strategy, it is expected that industrial establishments will achieve significant savings in material cost, which will create a benefit for new markets and increase the GDP of the EU by 3.3%. It is also emphasized in the report that waste prevention, reuse and recycling activities will decrease greenhouse gas emissions by 2–4%. With these advantages of the zero waste strategy, the CE is seen as an important instrument for sustainable growth with the CE zero waste approach in the rapidly growing eco-industry market (European Union Zero Waste, 2015). Within the scope of the zero-waste programme, it is aimed to reach 65% in domestic wastes, 80% in packaging wastes, 60% in plastic, 90% in iron material, aluminium and glass in terms of recycling by 2030 (Veral and Yiğitbasioğlu, 2018).

In Turkey, waste has increasingly become a major national issue due to factors such as the damage caused by the rapidly increasing urbanization and industrialization along with population growth. In order to control the amount of waste, waste regulations and action plans have been put into effect by the Ministry of Environment and Urbanisation in the light of EU directives. However, the rates of waste prevention, reduction, reuse and recycling are still very low, and the waste disposal rate is high (Buzkan and Erman, 2020; Environmental Report, 2018). Demir et al. (2020) emphasized that lack of financial support is one of the difficulties in waste management in Turkey. While the recycling average of the Organisation for Economic Co-operation and Development (OECD) countries is 36%, this rate is 10% in Turkey (OECD, 2019; Solak and Pekkuşken, 2018). The problems encountered in solid waste management in Turkey have been researched through a survey. The survey found that financial and technical support deficiencies; information deficiencies about the local administration; resource, personnel and vehicle deficiencies; staff training deficiency; and insufficient social awareness towards environmental protection were the most important problems in solid waste management. In the report by Yetim (2014), it was emphasized that the recycling rate in Turkey was quite low compared with European countries. It was stated in the study that this was due to reasons such as insufficient solid waste separation facilities, insufficient collection intervention in the source, ineffective management of municipal warehouses and lack of investment in recycling. In this study, in order to determine if zero waste management in Turkey can be implemented successfully, the main barriers and difficulties of zero waste implementation have been examined.

In uncertain environments, deterministic methods do not always enable accurate modelling in the process of making relevant decisions. The fuzzy DEMATEL method uses human judgements about factors, which are generally uncertain and hard to estimate by crisp values. Since the interaction between the barriers affecting the zero-waste strategies cannot be expressed quantitatively, the DEMATEL method is expanded with the fuzzy set theory, and the fuzzy DEMATEL method is used in this study. The starting points behind the usage of the fuzzy DEMATEL method are:

- Due to the subjective nature of waste management barriers, it is hard to analyse interactions between them.
- Fuzzy DEMATEL provides a quantitative analysis of waste management barriers.
- The cause-and-effect relationships among these barriers can help decision-makers develop regulatory strategies in terms of zero waste management.

The number of studies conducted on zero waste and CE in Turkey is quite limited. The paper aims to develop a fuzzy DEMATEL methodology to investigate the barriers encountered at the operational level of zero waste management. This study highlights the significance of the research with the following points: (a) identification of the critical barriers, which has an important role in waste management practices; (b) defining the zero waste strategies in Turkey considering the scope of the circular economy; and (c) the expert judgement on the relationships of barriers encountered in zero waste management using the fuzzy DEMATEL computation process.

The remainder of this paper is organized as follows: the next section presents the relevant literature review considering barriers to waste management. The article then introduces waste management and zero-waste strategies in Turkey. This is followed by an explanation of the fuzzy DEMATEL method, the steps of the proposed methodology and the fuzzy DEMATEL results. The article continues with a discussion section and, finally, conclusions and future framework.

Literature review

The concept of the CE has increasingly attracted academics, municipalities and politicians, among others, in recent years. According to the study conducted by Reike et al. (2018), it is seen that the CE has concentrated/concentrates around some basic concepts, especially waste management and recycling. The CE aims to provide added value to the economy by minimizing the amount of waste to be released to the environment (Lacy and Rutqvist, 2016; Murray et al., 2017). In accordance with CE strategies, reducing or eliminating the generation of waste, encouraging recycling and improving waste recovery activities are the primary targets of advanced waste management (Jacobsen et al., 2018; Park et al., 2010).

Sustaining the CE model is possible with effective waste management. Furthermore, identification of the key barriers plays an important role in improving waste management practices. More recently, many researchers and practitioners have identified several potential barriers to the success of future waste management solutions. Veleva et al. (2017) developed a conceptual framework using Global Reporting Initiatives (GRI) that consists of 11 new measures of CE. They analysed eight biotech and pharmaceutical companies to investigate their zero waste management strategies. Ritzén and Sandström (2017) reviewed multi-dimensional and multi-domain barriers of CE underlying five main dimensions ('financial, structural, operational, attitudinal and technological') for companies. They found that attitude and knowledge integration between functions, value chain structure, technology, value and finance are the most important barriers for an industrial company. Crawford et al. (2017) introduced 22 construction barriers under four main strategies to enhance the environmental efficiency of construction and demolition waste management. They found that a lack of financial support, industry culture, limited funding and time of disposal of the waste and lack of education were barriers contributing to significant construction impacts. Yukalang et al. (2017) conducted in-depth interviews with different participants (academicians, residents, municipal, administrators and organizers) and SWOT analysis that assesses the internal and external factors, as well as future potential barriers for municipal solid waste. According to the views of focus groups, various barriers were categorized into six dimensions 'technical, organizational, social-cultural, financial, legal-political and population growth'.

Some MCDM methods have been employed by researchers to identify potential waste management barriers. Zhao et al. (2017) developed an integrated model employing the Grey-Delphi method and fuzzy VIKOR to select the most appropriate eco-industrial parks in China. Sub-criteria of eco-parks were selected by using the Grey-Delphi method and then the entropy weighting method was applied to the weight of criteria. Finally, the fuzzy VIKOR method was proposed to prioritize and evaluate all alternatives. Liu et al. (2017) reviewed municipal waste practices guided by the 3Rs (reduce, reuse and recycle) principles under the CE approach in China. Mahpour (2018) explored construction and demolition waste barriers categorized under three main perspectives and prioritized them using the fuzzy TOPSIS method. According to aggregation results of all aspects, 'agency and ownership issues', 'lack of integration sustainable waste management', and 'uncertain alternatives of moving towards CE' are barriers that should be taken into consideration. Huang et al. (2018) identified the existing barriers for construction and demolition waste implications that considered the 3R principles in China. Ruiz et al. (2020) reviewed the literature of CE in construction and demolition waste and described 14 key strategies for implementing construction and demolition waste practices. All relevant CE strategies compiled five life-cycle stages (pre-construction, construction and building renovation, collection and distribution, end of life, material recovery and production).

Campbell-Johnston et al. (2019) conducted 67 interviews to investigate the obstacles and barriers of the circular transition of three cities in Holland. Their analysis showed that voluntary agreements, high waste taxes and knowledge exchange were key barriers that can maintain the transition to CE. Kattoua et al. (2019) analysed survey data collected from 246 households in Palestine, consisting of gender, education level, age and residence type attributes of sustainable recycling barriers. They developed the chi-square test to find the relation between attributes and to investigate socio-economic indexes. Zhang et al. (2019) applied the fuzzy DEMATEL technique to investigate the cause-effect relationships between 12 smart waste management barriers, based on survey data from technology providers, technology users and the agency's perspective. According to the cause-effect diagram results for three types of stakeholders, lack of knowledge, lack of cultural and natural properties, and regulatory strength are the most important causal boundary. Paletta et al. (2019) implemented a survey of 364 manufacturing companies to explore technical, economic, legislative and social barriers and challenges based on the 3Rs principles. Singh et al. (2020) conducted a questionnaire-based survey to investigate the potential difficulties and drivers of e-waste management in Mumbai considering CE strategies. They concluded that the primary obstacle to the collection of e-waste is the lack of environmental awareness while the distance between e-waste generation points and recycling units is the least influential barrier. The identified barriers to waste management are summarized in Table 1.

Waste management in Turkey

Industrialization and migration from rural to urban areas has occurred with advances in technology, and the rapid population growth has created a negative impact on human health and the environment in Turkey. While the increase in production and consumption activities in Turkey causes excessive use of natural resources, wastes produced due to the increasing trend of consumption have reached threatening levels (Turan et al., 2009). Periodic waste action plans have been launched for the disposal, storage, transportation and recycling of waste without harming the environment. In Turkey, the Ministry of Environment and Urbanisation implements the waste regulations and action plans to prevent/reduce waste generation and protect the environment and natural resources in line with the European Union (EU) waste management policies.

In Turkey, many studies have intensively examined municipal solid waste management (Ayvaz-Cavdaroglu et al., 2019; Banar et al., 2009; Coban et al., 2018; Tinmaz and Demir, 2006; Turan et al., 2009; Rızvanoğlu et al., 2019). Furthermore, some researchers studied liquid waste (Gurbuz and Ozkan, 2019), medical waste management (Birpınar et al., 2009), hazardous waste (Utku and Erol, 2020; Yayintas et al., 2007) and food waste (Cakar et al., 2020). In the light of the literature, none of the studies has examined the challenges and difficulties of municipal waste in accordance with the zero waste strategies in Turkey.

Table 1. Literature reviews of the key barriers for waste management.

The key barriers	Literature reviews
Lack of financial support and budget	Zhang et al. (2019); Mittal and Sangwan (2014); Yukalang et al. (2017); Campbell-Johnston et al. (2019); Veleva et al. (2017); Singh et al. (2020); Kumar and Dixit (2018b).
Inadequate waste regulations and policy	Yukalang et al. (2017); Zhang et al. (2019); Mittal and Sangwan (2014); Abba et al. (2013); Li and Yu (2011)
Lack of environmental awareness	Yukalang et al. (2017); Kumar and Dixit (2018b); Singh et al. (2020)
Lack of communication between stakeholders	Zhang et al. (2019); Yukalang et al. (2017); Campbell-Johnston et al. (2019); Veleva et al. (2017)
Lack of effective information management	Huang et al. (2018); Yukalang et al. (2017); Veleva et al. (2017); Kumar and Dixit (2018a)
Waste has no value	Yukalang et al. (2017)
Limited available facilities for collection and separation	Kattoua et al. (2019); Chauhan et al. (2018)
Inadequate second-hand market	Huang et al. (2018); Campbell-Johnston et al. (2019)
Insufficient recycling technologies	Huang et al. (2018); Kattoua et al. (2019)
Inadequate waste separation facilities	Yukalang et al. (2017); Kumar and Dixit (2018a)
Inadequate recycling options	Crawford et al. (2017)
Insufficient budget for separation	Crawford et al. (2017); Chauhan et al. (2018); Kumar and Dixit (2018a)
Lack of waste collecting points	Yukalang et al. (2017); Singh et al. (2020)
Uncertainty of goals and strategies related to CE	Yukalang et al. (2017); Kattoua et al. (2019); Veleva et al. (2017); Yuan (2017)
Insufficient waste separation, transportation and recycling processes	Dumlao-Tan and Halog (2017); Veleva et al. (2017); Kumar and Dixit (2018a, 2018b)
Inadequate and weak legislation	Yukalang et al. (2017)
Inadequate waste collection vehicles	Yukalang et al. (2017)
The limited capacity of existing facilities	Kattoua et al. (2019)
The failure of environmental education	Zhang et al. (2019); Veleva et al. (2017)
Inappropriate media	Yukalang et al. (2017)

CE: circular economy.

Municipal waste management towards the zero-waste vision

In 2020, municipal waste generation within the OECD regions was closer to 1.30 population (billions) in OECD (Index). In addition, the total generation of municipal waste within the OECD area is estimated to increase from 800 million tonnes/year to 900 million tonnes/year between 2020 and 2030 (Municipal Waste Generation, 2015). While OECD countries generated an average of 524.7 kilograms of municipal waste per capita in 2018, Turkey produced 413 kilograms per capita in 2018. In view of this data, the average amount of municipal waste collected and treated by municipalities is lower than the average produced waste in the OECD region (OECD Municipal Waste, 2020).

The amount of waste generated in Turkey has gradually increased during the last 16 years. The quantity of waste collected by municipalities was approximately 35,000,000 tonnes for 2018, and per capita waste is calculated as 1.16 kg per day (TurkStat, 2018). The annual average amount of municipal waste has gradually increased over the period 2002–2017 by 28% (Figure 1). In addition, the percentage of waste sent to controlled landfill sites was 27.8% in 2002, and it increased to 67.2% in 2018. According to Figure 1, only 11.9% of 35 million tons of municipal waste was sent to recovery facilities in 2018 (TurkStat, 2018). The recycling rate is 36% in the OECD countries while it is 10% in Turkey. The rest of the municipal waste

(90%) is sent to landfill sites or burned in the environment (OECD Environment Performance Reviews, 2019). Disposal of municipal waste without recycling processes causes loss of valuable raw materials and economic opportunities. The economic value of recycling waste buried in the soil is over 2 billion Turkish liras. According to a survey conducted by TurkStat (2018), there was a total of 2223 facilities including 166 waste disposal facilities and 2057 recycling centres in 2018. A total of 47 million tons of metal, plastic, paper, and similar wastes were recycled at the 2009 licensed recycling facilities.

However, despite the number of environmental regulations and measures, waste management does not live up to expectations of CE in Turkey. There is a need for the most effective policies and strategies to promote waste reduction and pollution prevention in Turkey; therefore, the ‘Zero Waste Action Plan’ 2023 was initiated by the Turkish Ministry of the Environment and Urbanization in 2017. The Ministry of Environment and Urbanisation made it obligatory to obtain a Zero Waste Certificate for public institutions and organizations with 500 to 1000 employees, municipalities with a population of over 100,000, shopping malls, airports, ports and 4- and 5-stars hotels (Zero Waste, 2020).

Turkey’s zero waste strategies aim to collect waste separately from the production source, to improve recycling efforts and to prevent wastage. This strategy provides conscious production and consumption to protect natural resources and contribute to economic growth through the use of natural resources and

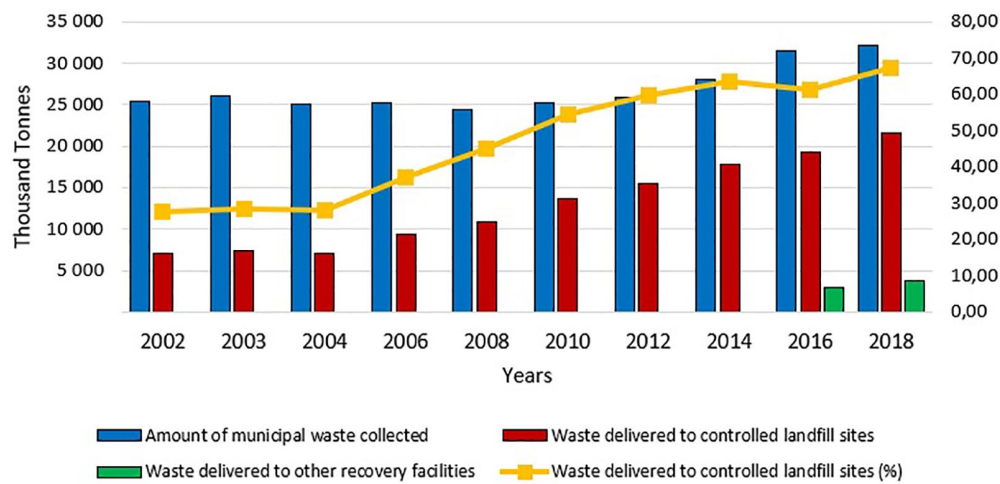


Figure 1. The amount of municipal waste and controlled landfill sites during 2002–2018.
Source: TurkStat, 2018.



Figure 2. Zero waste cycle process in Turkey.
Source: Zero Waste, 2020.

ecosystems within the scope of CE. The whole process of Turkey's zero waste management is summarized in Figure 2.

In 2016, 9.2% of waste was collected separately at the source (TurkStat, 2018). According to the target of the zero-waste action plan, collection rates will increase to at least 12% in 2023, 35% of the waste will be recycled and 65% is expected to be sent to municipal disposal areas. The recycling ratio of municipal waste will increase by 35% over 2014–2023. In order to achieve success in the zero-waste action plan and increase the waste recycling rate, household wastes should also be separated at their source and collected with this system. Turkey carries out its work with public and private sector cooperation to achieve the goals that support the implementation of the European Commission's circular economy strategy.

Waste management barriers

The qualitative step of this research included 12 important waste management barriers. These barriers are determined with respect

to the literature review and the opinions of the experts. They include 20 experts comprising two environmental engineers working in the Turkey Ministry of Environment and Urbanisation, two chemical engineers and 16 environmental engineers working in waste coordination branch offices in various municipalities in Turkey. The detailed profile of experts is shown in Table 2. Questionnaires were distributed to the 20 experts by email and conducted over a two-month period from January to March 2020. The majority of experts constitute municipal officials who worked in the capital of Turkey, Ankara. Other participants are people working in municipalities in Istanbul, which is the most populous city in Turkey, and in Çanakkale provinces. All key zero waste management barriers are identified and detailed in Table 3.

The fuzzy DEMATEL method

DEMATEL is a comprehensive method for building and analysing a structural model involving causal relationships between

Table 2. Detailed profile of the experts.

Organization	Branch	No. of respondents	Experience
Republic of Turkey Ministry of Environment and Urbanisation	Environmental Engineers	2	8 years
Waste coordinator branch office of the municipality	Chemical Engineer	1	More than 12 years
Municipal waste management branch	Chemical Engineer	1	More than 7 years
Municipal waste management branch	Environmental Engineers	16	At least 3 years

Table 3. Zero waste management barriers.

Barriers	Description	Reference(s)
B1: Lack of financial and economic aid	Waste fees, including the public's ability and willingness to pay and the ability for the collection of fees by the municipality, and refers to the public's attitude to the value of waste.	Yukalang et al. (2017); Kumar and Dixit (2018a); Zhang et al. (2019), experts
B2: Deficiencies in the legislation and standards on waste	Lack of regulatory pressures and unclear definitions for waste management.	Yukalang et al. (2017); Paletta et al. (2019)
B3: Lack of awareness regarding the environment	Low sensitivity to the environment due to the lack of environmental awareness.	Yukalang et al. (2017); Kumar and Dixit (2018a); (Singh et al. 2020)
B4: Lack of cooperation between stakeholders	Not enough stakeholder cooperation to encourage managers to adopt waste management. Stakeholder cooperation includes sharing responsibilities.	Zhang et al. (2019); experts
B5: Insufficient effective areas for waste collection and separation	Lack of appropriate locations to put waste, an insufficient number of collection points and points not sited appropriately.	Yukalang et al. (2017); experts
B6: Inadequate recycling techniques	Lack of innovation in recycling and low efficiency in recycling systems.	Paletta et al. (2019); experts
B7: Uncertainty about circular economy targets and strategies	Poor planning about challenges to CE and the absence of key strategies.	Yukalang et al. (2017); Kattoua et al. (2019)
B8: Lack of temporary holding sites	Insufficient number of temporary storage points	Kumar and Dixit (2018a); experts
B9: Insufficient methods for sorting, transporting and recycling waste	Irregularity of waste decomposition, insufficient waste separation processes	Kattoua et al. (2019); Kumar and Dixit (2018a)
B10: Inadequate sanctions and fines	Weaknesses in environmental regulations and insufficient monetary sanctions.	Zhang et al. (2019); experts
B11: Insufficiency in awareness regarding environmental protection	Low consciousness on environmental awareness and unsustainable cultural behaviour.	Veleva et al. (2017); Zhang et al. (2019)
B12: Insufficient advertising and media coverage for waste management	The situation in which information dissemination methods are ineffective in reaching households and residents.	Yukalang et al. (2017); experts

CE: circular economy.

complex factors (Wu and Lee, 2007). It is especially practical and useful for visualizing the structure of complicated causal relationships with matrices and diagraphs. These diagraphs portray a contextual relationship between the elements of the system, in which a numeral represents the strength of influence (Tseng, 2009).

But in decision-making problems related to the real-world, the evaluation given by experts or decision-makers on qualitative criteria is always expressed in verbal expressions instead of crisp values. Such linguistic evaluations are vague, which makes further analysis hard to compute. Thus, a fuzzy set theory can be implemented to measure uncertain concepts associated with subjective judgements (Zhou et al., 2011). Hence, fuzzy DEMATEL, a fuzzy set extension to the standard DEMATEL technique, was used in this research.

The fuzzy DEMATEL method is used by many researchers in the literature (Büyüközkan and Çifçi, 2012; Chang et al., 2011; Tseng, 2009; Wu and Lee, 2007) considering the fact that human judgement about preferences is often unclear and hard to estimate by exact numerical values.

The procedure of the fuzzy DEMATEL method consists of the following steps (Venkatesh et al., 2017; Zhang et al., 2019):

Step 1: Forming the fuzzy direct relation matrix (D)

In this step, the fuzzy direct relation matrix D is obtained by pair-wise comparisons of experts in terms of influences and directions between barriers, in which d_{ij} is denoted as the degree to which

barrier i affects the barrier j ; that is, $D = [d_{ij}]_{n \times n}$. The linguistic variables and their corresponding fuzzy numbers are used in this study on a scale from no influence to very high influence (0,0,0.25: no influence, 0,0.25,0.50: very low influence, 0.25,0.50,0.75: low influence, 0.50,0.75,1: high influence and 0.75,1,1: very high influence) (Wu and Lee, 2007).

Fuzzy triangular numbers (TFNs) were used to represent linguistic terms. Each TFN has three parameters in which l , m and u specified the smallest possible, the most promising and the largest possible value, respectively (Seçme et al., 2009).

Suppose $A_{ij}^k(l_{ij}^k, m_{ij}^k, u_{ij}^k)$ where $1 \leq k \leq K$ to be the fuzzy evaluation that the k th expert's opinion about barrier i impact on barrier j . The CFCS (Converting Fuzzy data into Crisp Scores) defuzzification method is used for the fuzzy aggregation process in this study (Opricovic and Tzeng, 2003). The CFCS method involves a four-step algorithm as in the following equations (1)–(7).

Normalization.

$$xl_{ij}^k = (l_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max} \quad (1)$$

$$xm_{ij}^k = (m_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max} \quad (2)$$

$$xu_{ij}^k = (u_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max} \quad (3)$$

where $\Delta_{\min}^{\max} = \max u_{ij}^k - \min l_{ij}^k$

Compute right and left normalized values.

$$xrs_{ij}^k = xu_{ij}^k / (1 + xu_{ij}^k - xm_{ij}^k) \quad (4)$$

$$xls_{ij}^k = xm_{ij}^k / (1 + xm_{ij}^k - xl_{ij}^k) \quad (5)$$

Compute total normalized values.

$$x_{ij}^k = [xls_{ij}^k (1 - xls_{ij}^k) + xrs_{ij}^k \times xrs_{ij}^k] / [1 - xls_{ij}^k + xrs_{ij}^k] \quad (6)$$

Obtain the crisp values. Following that, fuzzy numbers were converted to crisp values by using equation (7)

$$Z_{ij}^k = \min l_{ij}^k + x_{ij}^k \times \Delta_{\min}^{\max} \quad (7)$$

Finally, equation (8) is used to aggregate the experts' judgements where k is the number of experts

$$Z_{ij} = \frac{1}{K} (Z_{ij}^1 + Z_{ij}^2 + \dots + Z_{ij}^K) \quad (8)$$

Step 2: Normalizing the initial direct relation matrix (X)

The normalized initial direct relation matrix is calculated by equations (9)–(10).

$$X = s.D \quad (9)$$

$$s = \min \left[\frac{1}{\max_i \sum_{j=1}^n |d_{ij}|}, \frac{1}{\max_j \sum_{i=1}^n |d_{ij}|} \right] \quad (10)$$

Step 3: Obtaining the total relation matrix (T)

The total relation matrix (T) is calculated by using equation (11), in which the I is denoted as the identity matrix.

$$T = X(I - X)^{-1} \quad (11)$$

Step 4. Calculating D and R values

The sum of rows (D) and the sum of columns (R) are calculated by equations (12)–(14).

$$T = [t_{ij}]_{n \times n} \quad (12)$$

$$D = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1} \quad (13)$$

$$R = \left[\sum_{i=1}^n t_{ij} \right]_{1 \times n} \quad (14)$$

Step 5. Generating the cause-effect diagram

The cause-effect diagram can be acquired by mapping the dataset of $(D+R, D-R)$, where the horizontal axis ($D+R$) is made by adding D to R , and the vertical axis ($D-R$) is made by subtracting R from D (Chang et al., 2011). The prominence value is the sum of the causal influence (D) and the effect influence (R). A factor with a high prominence value is an important factor that affects another factor, while it may also be affected by the other factors (Zhu et al., 2014). A barrier falls into the cause group if its $(D-R)$ value is positive. Conversely, a barrier falls into the effect group if its $(D-R)$ value is negative (Lin, 2013).

Case study

This paper aims to develop a novel research methodology for potential barriers to zero waste strategies in the concept of the CE based on the knowledge of experts and previous studies. A list of 12 barriers was obtained from experts working in the waste coordination department of the municipalities and related literature studies. Questionnaires were distributed to 20 experts by email and conducted over a two-month period from January 2020 to March 2020.

In this study, we have used the fuzzy DEMATEL method to explore the cause-and-effect relationship among the potential barriers affecting the strategic planning and implementation of the CE-based zero waste management. In addition, the use of fuzzy DEMATEL helps to visualize the complicated interrelationship among the barriers and their degrees of influence and

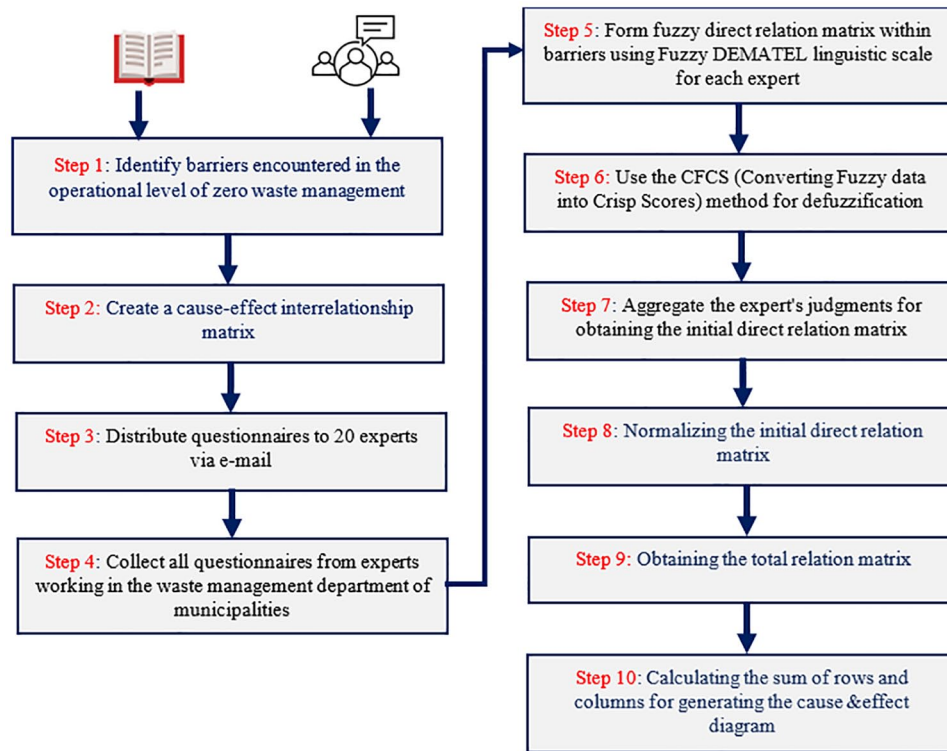


Figure 3. Steps of the proposed methodology.

Table 4. Total relation matrix for zero-waste barriers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.4098	0.4231	0.5303	0.4827	0.5932	0.4905	0.4638	0.5448	0.5910	0.3833	0.5127	0.5298
B2	0.3960	0.3320	0.4693	0.4377	0.4904	0.3952	0.4314	0.4376	0.5183	0.4007	0.4745	0.4352
B3	0.4891	0.4557	0.5033	0.5512	0.5744	0.4784	0.5372	0.5283	0.6107	0.4525	0.5707	0.5640
B4	0.4520	0.4345	0.5285	0.4158	0.4379	0.4407	0.4883	0.4757	0.5410	0.3922	0.4908	0.4970
B5	0.4983	0.4558	0.5477	0.5141	0.4916	0.4715	0.4853	0.5504	0.6034	0.4090	0.5050	0.4972
B6	0.4590	0.4081	0.5102	0.4541	0.5308	0.3649	0.4580	0.4701	0.5442	0.3593	0.4540	0.4547
B7	0.5114	0.4838	0.5793	0.5445	0.5933	0.4966	0.4392	0.5287	0.6063	0.4428	0.5302	0.5184
B8	0.4442	0.3780	0.4894	0.4625	0.5451	0.4235	0.4387	0.3980	0.5521	0.3653	0.4533	0.4484
B9	0.4976	0.4445	0.5593	0.5198	0.5962	0.4916	0.4950	0.5308	0.5065	0.4106	0.4990	0.4997
B10	0.3939	0.3902	0.4099	0.4349	0.4644	0.3788	0.4098	0.4312	0.5016	0.3031	0.4407	0.4314
B11	0.4513	0.4472	0.5766	0.5109	0.5456	0.4403	0.4833	0.4852	0.5569	0.3979	0.4328	0.5192
B12	0.4607	0.4160	0.4002	0.4093	0.4220	0.4332	0.4662	0.4657	0.4459	0.3866	0.4183	0.4168

impacts on the CE-zero waste practices. Since the interaction between the barriers affecting the zero waste strategy cannot be expressed quantitatively, the fuzzy DEMATEL method was adopted for this study. The overall framework of this study is illustrated in Figure 3.

Fuzzy DEMATEL results

The fuzzy DEMATEL method surveyed 20 experts to assess the relationships between barriers found in zero waste management. The influences between the barriers were calculated mainly by the experts. Then using equations (1)–(7), the fuzzy direct relation matrices generated by each expert were defuzzified. Finally, the views of the 20 experts were combined by utilizing equation (8). After the operations seen in equations (9)–(11) the combined

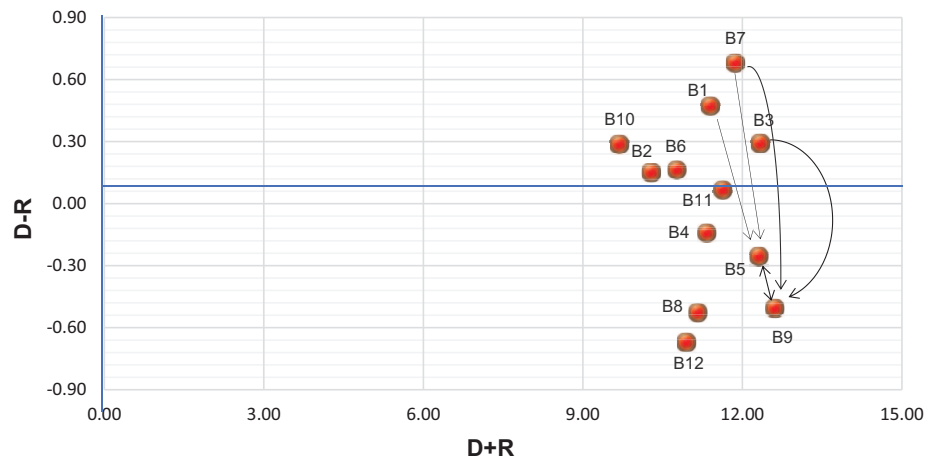
direct relation matrix was modified to the total relation matrix (T) as seen in Table 4.

The threshold value was determined by adding 2 standard deviations to the mean of the total relation matrix. Hereby, the threshold value was calculated to be 0.592 [$0.47 + (2 * 0.061)$]. The values greater than 0.592 are highlighted in bold in Table 4. This value was used to evaluate the significant relationships between the barriers. Table 5 was generated to illustrate the impact diagram by collecting quantities of rows and columns in the total relation matrix. The impact diagram developed with the values $D+R$ and $D-R$ in Table 4 is seen in Figure 4.

The significant relationships between the barriers are depicted with arrows in Figure 4. According to Figure 4, there was a significant relationship between B1 and B5, B3 and B9, B5 and B9, B7 and B5, B7 and B9.

Table 5. Group effect for all barriers.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
<i>D</i>	5.935	5.218	6.315	5.594	6.029	5.467	6.275	5.318	6.051	4.990	5.847	5.141
<i>R</i>	5.463	5.069	6.024	5.737	6.285	5.305	5.596	5.847	6.558	4.703	5.782	5.812
<i>D+R</i>	11.398	10.287	12.339	11.332	12.314	10.772	11.871	11.165	12.608	9.693	11.629	10.953
<i>D−R</i>	0.471	0.150	0.291	−0.143	−0.256	0.162	0.678	−0.528	−0.507	0.287	0.065	−0.671

**Figure 4.** Fuzzy DEMATEL cause-effect diagram of zero waste management in Turkey.

Discussion

The prominence value is the sum of the causal influence (*D*) and the total effect influence (*R*). The value of *D* and *R* are derived from equation (13) and equation (14), respectively. A factor with a high prominence value is an important factor that affects another factor, while it may also be affected by other factors (Zhu et al., 2014). Values of (*D+R*) and (*D−R*) were calculated for each barrier for zero waste implementation. The value of (*D+R*) expresses ‘prominence’ or ‘importance degree’ of each barrier. If the (*D+R*) value is higher, the important effects of the barrier and the interaction between the other barriers are greater. The value of (*D−R*) represents the ‘relationship’ between the barriers and can be grouped into two classes: the effect group and the cause group. Positive values of (*D−R*) belong to the cause group, which implies that these values are independent, while the negative values of (*D−R*) are included in the effect group, which means these values are influenced by causal group values. In the light of these results, Figure 4 represents the cause-effect relation diagram for barriers.

Analysis of cause-and-effect barriers

In order to investigate the barriers in the implementation of zero waste management, it is highly important to determine the cause-and-effect barriers. Seven barriers sorted according to their positive relation score (*D−R*) are as follows: $B7 > B1 > B3 > B10 > B6 > B2 > B11$. These causal barriers can play an important role in influencing the overall zero waste strategies in Turkey. Uncertainty about circular economy targets and strategies (B7),

Lack of financial and economic aid (B1), Lack of awareness regarding the environment (B3) and Inadequate sanctions and fines (B10) are the four most important barriers that have a critical impact on other barriers.

It can be clearly seen in Figure 4, ‘Uncertainty about circular economy targets and strategies’ has the ultimate value (0.678) among the barriers in the cause group, because it has the highest (*D−R*) value. At the same time, this barrier has the second-highest *D* value (6.275) among all barriers. This means that ‘Uncertainty about circular economy targets and strategies’ has a significantly high effect on preventing the success of zero waste management carried out by municipalities in Turkey. As the CE is a notably new concept in developing countries, the CE goals and strategies are not well understood in these countries (Ngan et al., 2019). The CE is still a new concept in Turkey, so Turkey carries out activities aimed at increasing awareness about the circular economy. In Turkey, the full implementation of the circular economy depends on a long-term study that predicts the effective participation of governments, local authorities, business and all layers of society (Varır and Gürtepe, 2018). Additionally, establishing robust targets, innovative and smart strategies are noticeably effective solutions for advancing the adaptation of zero waste/circular economy practices (Veleva et al., 2017).

According to the cause-effect diagram, B1: ‘Lack of financial and economic aid’ has the second highest importance value (0.471) among all causal barriers. Hence, ‘Lack of financial and economic aid’ has a remarkable impact on the implementation of zero waste. Most of the municipalities, which are the most important stakeholders responsible for waste management, do not have the financial power and sufficient institutional capacity to meet

the costly investments required by waste management. The most important reasons for financial problems are the insufficient budget provided by the Turkish central government for municipalities and insufficient amount of environmental tax (Buzkan and Erman, 2020; Solak and Pekküküşen, 2018). Moreover, the third most important causal barrier is 'B3: Lack of awareness regarding the environment' and it has the largest influential value (6.315) among all the barriers. The implementation of zero waste management in Turkey was quite challenging because of consumers' lack of awareness about zero-waste recycling and having less knowledge about environmental protection and policies. Omurbek et al. (2019) emphasized that university students have insufficient knowledge about zero waste management and their level of environmental awareness is low. In order to achieve success in zero waste management in Turkey, environmental awareness should be created in all segments of society.

To increase the awareness of zero waste management, companies can offer environmental awareness training programmes for their employees and collaborate with stakeholders in a joint project (Tezel and Yıldız, 2020).

Then, 'B10: Inadequate sanctions and fines' ranks the fourth among all causal barriers in the whole system, but it has a lower importance value (9.629). This means that inadequate sanctions and fines have a low impact on the whole barrier to achieving zero waste. It has been observed that the regulations and practices for the recycling of wastes to the Turkish economy are insufficient (Buzkan and Erman, 2020; Rızvanoğlu et al., 2019). Enforcement of sanctions and heavy fines should be implemented to prevent the removal of unregistered waste from its source (Aydın, 2019).

Although, B2: 'Deficiencies in the legislation and standards on waste', B6: 'Inadequate recycling techniques' and B11: 'Insufficiency in awareness regarding environmental protection' are involved in the causal group, they have a low importance value among all the zero waste barriers. B2: 'Deficiencies in the legislation and standards on waste' has low $D+R$ (10.287). It is seen that the technical infrastructure for zero waste recycling in municipalities is not a factor that significantly affects zero waste management.

When analysing the relationship matrix, effect barriers can be ranked in accordance with their influence levels as follow: $B12 > B8 > B9 > B5 > B4$. It was observed that B12: 'Insufficient advertising and media coverage for waste management' is the most affected barrier $D-R = -0.671$ for the implementation of zero waste management. 'B8: 'Lack of temporary holding sites' has the second-highest ($D-R$) effect value (-0.528) among all of the barriers. At the same time, B8 is the fourth important barrier ($R = 5.847$) influenced by others. Moreover, B9: 'Insufficient methods for sorting, transporting and recycling waste' with the maximum ($D+R$) value was the most prominent barrier among other barriers. B9 also has the third-highest degree of influential impact value (-0.507). According to the direction of the arrows depicted in Figure 4, B9 is greatly influenced by the barriers B7: 'Uncertainty about circular economy targets and strategies', and B3: 'Lack of awareness regarding the environment'. In addition, B9: 'Insufficient methods for sorting, transporting and recycling waste' and B5: 'Insufficient effective areas for waste collection

and separation' have affected each other. Meanwhile, the barrier B9 has the highest interaction value (12.608) of the entire model. This means that B9 is greatly affected by all barriers in the zero-waste system. Then, B5: 'Insufficient effective areas for waste collection and separation' is the prominent barrier as stated in ($D+R$) value (12.314). Furthermore, this barrier is the second most affected barrier among all barriers and B5 is impacted by B1: 'Lack of financial and economic aid' and B7: 'Uncertainty about circular economy targets and strategies'. B4: 'Lack of cooperation between stakeholders' is located near the causal group with the $D-R$ value (-0.143) and it has relatively small value compared to other affected barriers.

Conclusion and future framework

Recently, zero waste principles adopted in the framework of circular economic development and the zero waste project have been implemented in Turkey, and zero waste management related projects have been implemented by public and private enterprises. Turkey's zero-waste practices are gaining momentum because of the desire to attain circular economic goals and meet international environmental regulations. However, existing barriers cause difficulties in the implementation of zero waste management. The proper identification and analysis of these potential barriers are important issues for the success of waste management. To our knowledge, no studies have previously examined the critical barriers affecting the strategic planning and implementation of the Turkish circular economy-based zero waste management.

In order to fill this gap in the literature, we develop an effective method to investigate potential barriers to the practical implementation of zero waste based on the cause-effect relation diagrams. For this purpose, we identified 12 potential barriers that need to be assessed, and then the fuzzy DEMATEL method was applied in the uncertain environment to understand the hierarchical and contextual relationship structure among the barriers to zero waste management. The power of the proposed method is that it can visualize the problems with the cause-effect relationships diagram where the importance of each causal barrier is shown. In addition, this model helps stakeholders and authorities to understand the critical barriers for efficient zero waste management in Turkey. Another strength of this model is that DEMATEL extended with fuzzy theory was used to eliminate the subjectivity and uncertainties caused by the decisions of the experts.

Based on the key barriers affecting the achievement of the zero-waste concept in Turkey, this study reveals the following management implications from the perspective of government and municipalities:

1. 'Ambiguity and the goals and tactics relevant to the circular economy' is the most effective and causal barrier as a result of fuzzy DEMATEL. Therefore, it should be emphasized in the goals and strategies of CE by the government and local authorities for successful and efficient zero waste management in Turkey. In addition, CE is an approach based on reducing raw material usage and waste amount with a holistic approach by

changing the design, production and use of the product. Waste management is a part of the transition on the road to a CE. Zero waste management aims to manage resources efficiently by prevention, minimization of the amount of waste, and recovery of raw material and energy. Thanks to the strict goals and targets of CE, the goal of zero waste has been achieved with the recycling and reuse of its products.

2. The lack of organizational and social support and lack of awareness regarding the environment are the critical barriers affecting the overall zero waste management system. In light of this result, developing environmentally sensitive projects within the framework of social responsibility is an important factor in the success of zero waste management. In order to develop environmental awareness of waste management, environmentally friendly projects should be supported, and further cooperation should be encouraged by various public enterprises and municipal corporations.
3. 'Insufficient advertising and media coverage for waste management' is the least important barrier militating against effective zero waste management.

One limitation of our implementation is that data were gathered only from the experts working in municipalities and government agencies to evaluate the cause-effect relationship matrix. This study does not consider the views of stakeholders working in the private sector. Future studies could investigate the association among different types of stakeholders and make pairwise comparisons among the potential barriers to judge their cause-effect relationships. Additionally, it is important for future research to investigate the structural relationships among barriers to find significant influence barriers to zero waste management. Hence, further studies are offered to address the limitations mentioned above and can be adapted to structural equation modelling (SEM) to enhance the validity of the proposed model.

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