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RESEARCH ARTICLE

A facilitating framework for a developing country to adopt smart waste management in the context of circular economy

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Abstract

To achieve higher standards of sustainability, the waste management sector now requires the incorporation of circular economy (CE) principles. However, an easy transition toward the particular goal would require the use of smart waste technologies. To achieve the aforementioned goal, this study aims to provide a facilitating framework for the adoption of smart waste management in the context of CE for Pakistan. To help Pakistan transition toward the new paradigm, a total of 16 critical facilitators are evaluated based on five distinctive criteria using a novel fuzzy hybrid multi-criteria decision-making (MCDM) approach. The hybrid MCDM approach includes fuzzy Stepwise Weight Assessment Ratio Analysis (SWARA) for allocating weights to the determined criteria; whereas, the fuzzy VIšekriterijumsko kompromisno rangiranje (VIKOR) approach is used to rank the critical facilitators adopted from the secondary literature. The fuzzy approach in both cases is to deal with any kind of uncertainty during the data collection process. Based on the achieved results, the study suggests that before the application of smart waste technologies in the country, Pakistan should first focus on devising regulations that effectively address the mismanagement of waste produced in the country. Also, the industries in the country need to become more responsible and should adopt environmental management systems that foster waste minimization. Lastly, the country in the third phase should focus on the wide application of digitalization both in the streams of ICT and IoT, for collecting, sharing, and receiving waste data. The study further provides policy recommendations to the respective stakeholders that will help the country achieve zero-waste CE.

Keywords Waste management · Circular economy · Digitalization · Developing country · Fuzzy · MCDM

Introduction

Due to the ever-increasing population, there is a significant increase in the generation of solid waste around the world. Solid waste management has become a serious problem not only for developed countries but also for developing nations as well. The term “solid waste management” refers to the collecting, treating, and getting rid of solid waste material that no longer serves any purpose. Problems arise when waste is not managed or disposed of in an environmentally safe manner, which as a result creates unsanitary conditions that cause several diseases. Solid waste management is a complex task that poses several challenges in the shape of social, administrative, and economic problems. Currently, the world generates around 2.01 billion tons of municipal solid waste; however, this number is expected to rise to 3.4 billion tons by 2050. In the current 2.01 billion tons of solid waste generated, about 33% of the waste is not managed in an environmentally safe manner (The World Bank 2019). For effective waste management, technological advancement in the waste management sector started in the early nineteenth century. Initial practices primarily focused on incineration and primordial disposal methods such as open dumping on land or in water. However, due to the negative impact of incineration and landfilling on the environment, modern practices are leaning more toward recycling rather than incineration and land disposal methods (Nathanson 2020).

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More recent development in waste management incorporate the CE approach, which gives a rather new perspective to the existing waste management practices. The CE approach primarily works on the 3R principle, i.e., reduce, reuse, and recycle policy (Ellen MacArthur Foundation 2013). Essentially, the CE approach aims at utilizing resources in the best possible manner to avoid waste and achieve resource efficiency. The particular approach further deals with the recovery of value from waste, aiming to achieve circularity in the usage of resources. In this case, the role of industries becomes really important to adopt business models based on the concepts of the circular and sharing economy. Sustainable waste management practices such as reusing, refurbishing, or recycling can be ensured through reverse logistic infrastructures. However, to aid these processes, the role of industry 4.0 or smart technologies has received considerable attention (Wilts et al. 2021, pp. 1–31). Smart waste technologies are in the streams of the Internet-of-Things (IoT), artificial intelligence (AI), and big data (Sarc, Curtis, Kandlbauer, Khodier, Lorber, and Pomberger Digitalisation and intelligent robotics in value chain of circular economy oriented waste management – a review 2019). The application of smart waste management technologies comes under the umbrella of smart cities. The aim of smart cities is to adopt cyberinfrastructure and industry 4.0 technologies to achieve sustainable development, thus, helping to achieve a better quality of life, resource efficiency, and economic growth (Ali et al. 2020). According to the United Nations, digital tools help enable waste management more efficiently. Also, using smart waste management technologies results in the reduction of carbon emissions by about 60% in cities. (Lenkiewicz 2016).

The inability to track daily waste created in cities and their effective collection and segregation is a challenging task. Furthermore, the municipalities, scavengers, and waste pickers are subjected to serious health risks because of ineffective waste management practices (Zolnikov et al. 2018). Hence, to tackle this issue, smart waste management is the most effective and suitable solution to this problem. Smart technologies in waste management primarily focus on the use of location-based technologies (e.g., GIS and GPS), data gathering technologies (e.g., sensors and imaging), identification-based technologies (e.g., barcodes and RFID), and finally, data transmission technologies (e.g., Bluetooth, Wi-Fi, and GSM). The last three among the abovementioned technologies are given the most attention (Esmaeilian, Wang, Lewis, Duarte, Ratti, and Behdad, The future of waste management in smart and sustainable cities 2018). RFID tags are effectively used for identifying waste, capacity sensors for identifying levels of waste, and actuators to close the bins once they are filled. Whereas, wireless devices are used to send waste data to the control center (Shyam et al. 2017). Among smart waste technologies, smart bins have also got considerable attention. These IoT-enabled smart bins use sensors along with other technologies such as actuators and motors to detect the level of waste along with the identification and segregation of waste (Mittal 2020). Hence, this benefits the municipalities and other organizations on the timely collection of waste. It also optimizes the routes for trucks that collect waste, resulting in fewer greenhouse gas emissions and reduced fuel consumption (Lozano et al. 2018). Several types of smart bins are being developed and are available in the market, each having its own set of properties. For example, there are smart bins that do not only focus on waste levels but also segregate the waste according to its type along with other benefits like eliminating the smell associated with the specific type of waste, etc. (Nižetić, Djilali, Papadopoulos, and Rodrigues, Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management 2019). However, smart waste management does not wholly solely depends on the adoption of smart bins but an amalgamation of several smart technologies working together to make the whole process of waste management more effective (Melaré, González, Faceli, and Casadei, Technologies and decision support systems to aid solid-waste 2017).

Solid waste management is a problem more prevalent in developing countries, and a country like Pakistan is no exception. According to an approximate, Pakistan generates around 48.5 million tons of solid waste each year, and there is an increasing rate of 2% each year (International Trade Administration 2019). The waste management infrastructure in Pakistan is seriously outdated, which creates some serious environmental threats. All the major cities of Pakistan face the same problem especially the metropolitan city Karachi, which produces around 13,500 tons of waste daily. Whereas, the rest of major cities cumulatively produces 87,000 tons of waste daily (International Trade Administration 2019). Due to the lack of administrative, institutional, and financial constraints, there is neither a proper collection nor disposal of municipal solid waste. The collection rate is about 60%, whereas the remaining 40% is left on the open grounds (Korai et al. 2020). The uncollected waste as a result poses serious health risks in the form of clogging drains, formation of stagnant forms, which results in providing a breeding ground for mosquitoes and flies, making diseases like malaria and cholera more prevalent. Whereas, the other collected waste is dumped openly into pits, ponds, rivers, and agricultural land (Shah et al. 2019). All of this is because of the lack of standard operating procedures to follow on waste management in the country. For example, lack of infrastructure, proper planning, government's will, and public awareness are some of the contributing factors (Azam et al. 2020).

To solve the abovementioned problems, Pakistan needs to revise and focus on its waste management practices and adopt sustainable smart waste technologies along with the principles of CE. However, the transition toward the particular goal would be hindered by regulatory, technical, and economic barriers. These barriers have been outlined and have been studied in the context of emerging countries like China and India, respectively (Zhang et al. 2019; Sharma et al. 2020). However, the literature is silent on providing a supporting framework for the adoption of smart waste management in the context of CE for Pakistan. Every country has its own set of policies and targets to achieve, and so it becomes very essential to formulate a country-specific framework to achieve the desired goal. Furthermore, a country like Pakistan is still in its infant stage when it comes to the concepts of CE. Also, studies based on sustainable smart cities especially in the context of developing countries like Pakistan are still untapped; therefore, the margin of contribution to the literature in the specific domain is quite considerable (Esmaeilian, Wang, Lewis, Duarte, Ratti, and Behdad, The future of waste management in smart and sustainable cities 2018). To facilitate sustainable waste management in Pakistan, the aim of this study is threefold. Firstly, through an extensive literature review, a list of critical facilitators for adopting smart waste management in the context of CE would be finalized with the help of experts. Secondly, a hybrid MCDM technique would be used to evaluate the critical facilitators based on five distinctive criteria, i.e., environmental, social, economic, technical, and regulatory perspectives. Lastly, based on the achieved results, policy recommendations would be given to respective stakeholders in the waste management sector of the country.

The rest of the paper is outlined in such a manner that Sect. 2 will comprise of literature review, followed by data collection and methodology in Sect. 3. Furthermore, Sects. 4 and 5 would include results and discussion and conclusion, respectively.

Literature review

With the increasing world population, waste management is becoming a challenging task for both developed and developing countries. However, developing countries face more challenges because of meager resources (Asase et al. 2009). The problem further worsens for developing countries because there is a growing CE trend in which recyclable and secondhand materials are exported from developed to developing countries, which as a consequence adds an additional burden on such countries. Therefore, developed countries need to work on their waste minimization and support the developing countries by transferring waste management and recycling technologies (Liu et al. 2008). There are three main stakeholders when it comes to waste management in a country. They include the government (municipalities), industries, and the social community. All these stakeholders need to work in a cohesive environment, where the ultimate aim should be to collaborate and achieve maximum sustainability. The aforementioned goal can be achieved through a cloud-based system, where all the stakeholders can access and receive waste data (Aazam et al. 2016).

The challenges faced by developing countries can be overcome through smart enabling waste technologies. Examples of these smart technologies include the usage of software, electronics, sensors, and actuators for the proficient processing and exchange of data. However, the adoption of these technologies comes with technological and R&D barriers when it comes to developing countries. Hence, developed countries need to work on collaborating with international researchers to fulfill the lack of local research (Melaré, González, Faceli, and Casadei, Technologies and decision support systems to aid solid-waste management: a systematic review 2017). Furthermore, other social, technical, and regulatory hindrances need to be tackled to effectively transition toward the use of smart waste technologies (Marshall and Farahbakhsh 2013). The usage of smart technologies would bring benefits such as efficient collection, sorting, and segregation of waste, along with abstaining waste pickers, municipality workers, and the general public from various health risks. In addition to this, these technologies would also help in enhancing the process of recovering value from the waste (Ramos et al. 2018), helping in meeting the SDG targets while enabling a more circular-oriented economy (Hannan et al. 2020).

Apart from the numerous benefits associated with the adoption of smart waste management, there are certain barriers faced by some countries. To cater to these barriers, countries like China, have already enacted laws to facilitate the transition toward CE. The supporting legislation law came in 2009, intending to bring resource efficiency, preserve the environment, and achieve sustainable development growth (Yong 2007). However, the country still faces certain barriers in the adoption of new technologies. These barriers are in the shape of regulatory and market pressures, and lack of environmental awareness (Zhang, Venkatesh, Liu, Wan, Qu, and Huisingh, Barriers to smart waste management for a circular economy in China 2019). Developing countries like India are also moving toward the concept of smart cities and the adoption of smart waste management technologies. However, the country faces certain barriers in its earlier phases. These barriers are analyzed through hybrid MCDM techniques involving the total interpretative structural modeling (TISM) approach, the fuzzy MICMAC model, and the DEMATEL method. The top critical barriers evaluated as a result were lack of regulations, standardization, and internet facility (Sharma et al. 2020).

Countries like Indonesia are also moving toward the adoption of smart waste technologies, particularly focusing on the usage of IoT technologies to identify, separate, and treat waste. (Fatimah et al. 2020). Adopting smart waste technologies is a step toward building smart cities. The concept of smart cities is still new and challenging to developing countries. To investigate such challenges, a study in the case of India has been conducted where the goal was to provide critical enablers that would help the country achieve its objectives. The critical enablers are ranked using a hybrid MCDM approach consisting of the BWM and ISM for an easy transition toward the building of smart cities. The results of the study suggest sustainable resource management and the development of smart buildings are the topmost enablers (Yadav et al. 2019). There are several factors that affects and influence the transition toward a circular-oriented waste management approach. These factors include social, economic, and regulatory indicators that need to be taken into account when devising a supporting framework. The formulation of a supporting framework needs to involve decision-makers and experts where the results should not be based just on theory (Salmenperä, Pitkänen, Kautto, and Saikku, Critical factors for enhancing the circular economy in waste management 2021).

This study aims to focus on the developing country, Pakistan, and how it can adopt the principles of CE through the adoption of smart waste management technologies. Pakistan has a huge potential when it comes to the incorporation of the CE approach in the waste management sector. The wide implementation of CE principles in waste management would help achieve sustainable development goals in the country (Tariq et al., 2021). However, a joint effort is needed where all the stakeholders including the society have to play their part (Ali et al. 2018a, 2018b). Recent literature on the waste management sector of Pakistan is limited and does not concentrate on the CE trend. A few of these studies include the determination of the most optimal way to manage the waste of the city, Lahore. For this purpose, a hybrid MCDM approach, i.e., fuzzy AHP-TOPSIS, is used to rank the best alternative. The results of which suggest anaerobic digestion to be the best alternative for treating the waste in the city (Ali et al. 2018a, 2018b). Lack of financial resources and data available on the production of waste generation in cities is the biggest problem for the regulatory bodies to devise a proper plan for solid waste management in Pakistan (Ilyas et al. 2017). Open dumping of waste is a serious problem in most of the cities of the country. To tackle this problem, proper supervision and monitoring of waste are very important for effective waste management in the country (Usman et al. 2017). The same problem is also prevalent in the twin cities of Islamabad and Rawalpindi, where ineffective waste management practices are causing several diseases among the people (Akmal and Jamil, Assessing health damages from improper disposal of solid waste in Metropolitan Islamabad–Rawalpindi, Pakistan 2021). In large cities like Karachi, around 70% of the waste goes to landfills, which causes significant pollution in the city. The city also lacks a proper system for recovering or recycling waste. Therefore, the country requires a proper and effective waste management system in which both the formal and informal sector needs to take part (Aslam et al. 2021).

When it comes to recovering value from waste, most of the recent studies in the context of Pakistan focus on waste-to-energy and incineration technologies (Siddiqi et al. 2019; Shah et al. 2021; Safar et al. 2021). However, the literature is still silent when it comes to the adoption of CE principles through the help of smart enabling technologies in the waste management sector of the country. This study fills in this gap by adopting and evaluating critical facilitators through which the country can engage in more sustainable waste management practices. The critical facilitators are evaluated based on five distinctive criteria, using a fuzzy hybrid MCDM approach. Over the years, several MCDM techniques have been developed and have been used in various studies. These MCDM techniques include TOPSIS, AHP, BWM, MARCOS, EDAS, and FUCOM, etc. Example of such studies includes the evaluation of e-service quality in the airline industry through the fuzzy AHP and MARCOS approach (Bakır and Atalık 2021). Whereas, the MARCOS methodology has been used in the selection of a supplier for a steelmaking company (Badi and Pamucar 2020). The selection of the most sustainable waste management technique in Nigeria uses the EDAS approach (Muhammad et al. 2021). The application of fuzzy TOPSIS has been seen in the selection of the most sustainable hybrid electric vehicle in the context of a developing country (Khan, Ali, and Khan, Sustainable hybrid electric vehicle selection in the context of a developing country 2020). A similar technique has been further applied in evaluating barriers in the adoption of CE for food waste management in the context of a developing country (Ali, Jokhio, Dojki, Rehman, Khan, and Salman 2021). Moreover, a combination of FUCOM and fuzzy QFD has been applied in assessing strategies for the enhancement of resilience in the health care sector of a developing country (Khan, Ali, and Pamucar, A new fuzzy FUCOM-QFD approach for evaluating strategies to enhance the resilience of the healthcare sector to combat the COVID-19 pandemic 2021). To deal with uncertainty in the decision-making process, fuzzy logic is used to overcome any ambiguity during the process (Ali et al. 2021a, 2021b). However, the hybrid MCDM approach used in this study for evaluating the critical facilitators is fuzzy SWARA and fuzzy VIKOR. The particular hybrid approach has been considered because of its simplicity and its unique set of advantages which are outlined in the subsequent paragraphs.

For the evaluation of criteria, the study uses fuzzy SWARA because of its unique set of advantages. The technique is widely used where the role of policymakers is of prime importance. Therefore, decision-makers have a key role when it comes to allocating weights to the criteria (Keršuliene et al. 2010). The technique proves to be very successful in conditions where policymaking is involved on a top level (Zolfani and Saparauskas, New Application of SWARA Method in Prioritizing Sustainability Assessment Indicators of Energy System, 2013). The significance of the considered methodology is its ability to give more accurate results as compared to other MCDM methods (Vafaeipour et al. 2014). SWARA has been used for determining the weights of the criteria in the railway management model (Vesković et al. 2018). It has been further used for the selection of a sustainable design for household furnishing materials, where the results of SWARA were compared with those of BWM. Where results of the study supported SWARA for achieving more consistent and robust results as compared to the BWM (Zolfani and Chatterjee, Comparative Evaluation of Sustainable Design Based on Step-Wise Weight Assessment Ratio Analysis (SWARA) and Best Worst Method (BWM) Methods: A Perspective on Household Furnishing Materials 2019). The technique has been further used in a renewable energy technology selection problem alongside the MULTIMOORA approach for ranking the alternatives (Maghsoodi et al. 2018). Furthermore, for the selection of a third-party logistic provider, fuzzy SWARA has been used for criteria evaluation along with fuzzy COPRAS for ranking the alternatives (Zarbakhshnia et al. 2018). For an outsourcing provider selection problem, the same approach has been used (Perçin, An integrated fuzzy SWARA and fuzzy AD approach for outsourcing provider selection 2019). Also, for the selection of a logistics center, the same approach has been used alongside with fuzzy Combined Compromise Solution (CoCoSo) method rank the best alternative (Alptekin et al. 2020).

For ranking the critical facilitator, this study uses the fuzzy VIKOR approach. The particular technique has been selected because of its unique set of advantages. The particular approach is capable of deriving the final ranking by taking both the "maximum group utility of the majority," which is a factor that corresponds to the utility of all relevant criteria. It also takes the minimum "individual regret of the opponent into consideration," which considers all the unsatisfactory criteria. The technique further helps the decision-makers in making irrational decisions based on the consideration of lower and higher performance ratings of viable alternatives (Chang 2014). Its usage in the literature involves its application for the selection of the most sustainable supplier selection for the beef industry (Meksavang et al. 2019). It has been further used for the evaluation of renewable technologies in India (Rani et al. 2019). The technique has also been used in combination with ANP for sustainable supplier selection. Where ANP is used for calculating weights of criteria, and VIKOR is used for ranking the alternatives along with using fuzzy triangular numbers (Baset et al. 2019). An integrated AHP-VIKOR has been further used for a multi-tier sustainable global supplier selection (Awasthi et al. 2018). Furthermore, for the evaluation of the green performance of the airports, the hybrid BWM-VIKOR approach has been used (Kumar, A, and Gupta 2020). Fuzzy VIKOR has been also used in combination with Modified-Safety Improve Risk Assessment (Modified-SIRA) for environmental assessment of E-waste management in the context of a developing country (Hameed et al. 2020). Further studies on fuzzy VIKOR and its application in waste management include (Kabir 2015; Utrillas, et al. 2015; Gündoğdu et al. 2019). Whereas, studies based on fuzzy SWARA-VIKOR have been used to compute ranking for cloud-based selection problems (Akbarizade and Faghihi 2017). The same approach has been further used for a solar panel selection problem (Rani et al. 2020).

From the studied literature, it can be derived that Pakistan does not have a sustainable framework incorporating the CE principles when it comes to the waste management sector. Therefore, the current situation in Pakistan regarding unsustainable waste management practices causes several environmental and health hazards. These practices further result in the loss of valuable waste which can otherwise be reused, refurbished, or recycled. Waste management is a complex and intricate sector; therefore, developing a sustainable framework for the particular sector requires the involvement of all stakeholders. Hence, the role of decision-makers or expert opinion, in this case, becomes really important (Torkayesh et al. 2021). Also, powerful decision-making techniques play a significant role when it comes to the evaluation of criteria and alternatives (Mi et al. 2021). To address all the abovementioned targets, this study aims to provide a facilitating framework for a developing country like Pakistan to adopt the CE principles in the waste management sector through the adoption of smart waste technologies. For this purpose, the study evaluates the critical facilitators to achieve the aforementioned goal through a fuzzy hybrid MCDM approach involving fuzzy SWARA and fuzzy VIKOR. The fuzzy logic in both cases is used to avoid or remove any kind of uncertainty in the decision-making process.

Data collection and methodology

The methodology developed involves several processes and steps that have been outlined in the flowchart in the shape of Fig. 1 below.

The data collection process involved both primary and secondary data. The first step of data collection involved secondary data, i.e., through an extensive literature review a total of 26 critical facilitators (alternatives) to the adoption of smart waste management in the CE, were

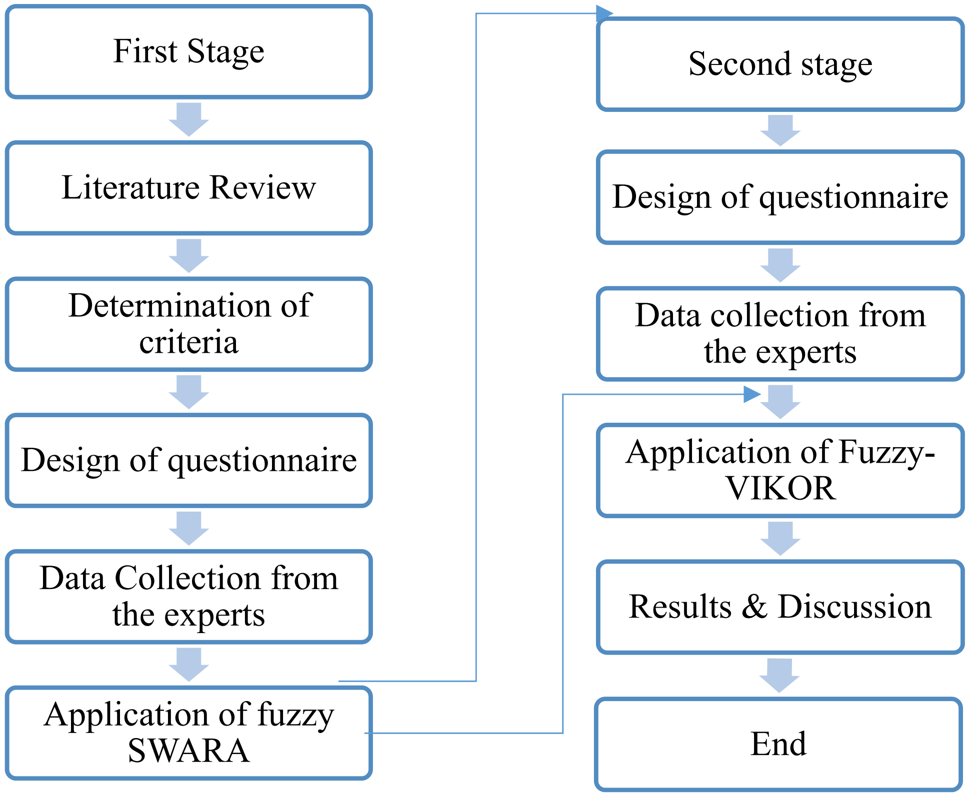

Fig. 1 Hierarchy of the developed methodology

determined. Thereafter, this number was further decreased to a final list of 16 critical facilitators through the help of experts. The role of the experts was to identify the most important facilitators and help remove the redundancy in the overall list. The list of finalized 16 critical facilitators is given in Table 1 below.

The next step in the data collection process was to collect data from the experts to rank the most critical facilitators based on their experience. The 16 facilitators were ranked based on five criteria that include (C1) environmental, (C2) social, (C3) economic, (C4) technical, and (C5) regulatory perspectives. A total of 33 experts took part in the survey. The average experience of the respondents was 10 years. Whereas, the expertise and the respective number of the respondents are summarized in Table 2 below.

A five-point Likert scale ranging from very low to very high was used to collect data from the experts. Using the fuzzy set theory, the linguistic variables were transformed in their respective fuzzy numbers. The particular theory was devised by Lotfi Asgerzadeh from the University of California in 1965 (Zadeh 1965). It is used to capture the vagueness involved when collecting data from the respondents. To allocate numbers to the linguistic variables, Asgarzadeh came up with a set of numbers ranging between [0, 1], all having nonnegative numbers.

For example, if C is a reference set having members belonging to (y), then the fuzzy set of A is shown with the help of the following equation:

$$C = \{(y, \mu c(y)) | y \in A \quad (1)$$

The membership function (y) belonging to (C) shows the degree of membership, as to how much (y) belongs to the fuzzy set of (C).

There are various shapes in fuzzy numbers, e.g., bell form, triangular, trapezoid, etc., but here, triangular fuzzy numbers will be used because of their simplicity. The triangular fuzzy numbers have three distance boundaries, i.e., lower, mean, and upper bound. The three variables (x, y, and z) along with the associated triangular shape is given in Fig. 2 below.

The membership associated with the fuzzy numbers is given in Eq. (2) below.

$$\mu_c(y) = \begin{cases} y - a/b - a & a \le y \le g \\ c - y/c - b & b \le y \le c \\ 0 & otherwise \end{cases} \quad (2)$$

Here $f, g,$ and$h$ are nonnegative numbers in the order of $a < b < c$. The value of y at f gives the maximum value, i.e., $\mu_c(y) = 1$; whereas, the value of y at h gives us the minimal

Table 1 List of critical facilitators for the adoption of smart waste management in the CE

S.no	Critical facilitators	References
1	Business models based on circular and sharing economy concepts	(Henry et al. 2021; Jabłoński and Jabłoński 2020; Schwanholz and Leipold 2020)
2	Supportive government policies	(Ferronato et al. 2019; Avdiushchenko and Zając 2019; Fedotkina et al. 2019)
3	Standard operating procedures to follow on waste management	(AdeolaIdowu et al. 2019; Blaisi 2019; Bui et al. 2020)
4	Educating and spreading awareness campaigns on circular economy and smart waste management	(Hartley et al. 2020; Vanapalli et al. 2021; Smol et al. 2020)
5	Transfer of waste for reutilization through an industrial symbiosis network	(Baldassarre et al. 2019; Abreu and Ceglia 2018; Ali et al. 2019a, 2019b, 2019c)
6	Wide application of digitalization for collecting, sharing, and receiving waste data	(Nižetić et al. 2019; Esmaeilian et al. 2018b, 2018a; Shyam et al. 2017; Chaudhari and Bhole 2018)
7	Incentivizing the procurement of smart waste technologies	(Zhang 2019; Ranchordás, 2020; Vohra et al. 2020)
8	Meeting society's expectations for corporate social responsibility	(Daú et al. 2019; Fortunati et al. 2020; Rashid 2020)
9	Environmental management systems	(Ikram et al. 2019; Papagiannakis et al. 2019)
10	Usage of appropriate methods or technologies to recover value from the waste	(Wainaina et al. 2020; Covidou et al. 2017; Quina et al. 2018)
11	An advanced research and development system	(Škrinjarić 2020; Cambier et al. 2020; Dipak and Aithal 2021))
12	Enhanced citizen participation and green behavior through reward-based systems	(Cardullo and Kitchin 2019a, 2019b; Kumar et al. 2020a, 2020b; Fetanat et al. 2019))
13	Smooth and uninterrupted internet facility and a strong cybersecurity system	(Kumar et al. 2020a, 2020b; Yadav et al. 2019; Ahad et al. 2020)
14	Business opportunities and a potential market for introducing smart waste technologies	(Fatimah et al. 2020; Nižetić et al. 2019; Appio et al. 2019))
15	Public–private partnership programs for smart waste technologies adoption	(Bao et al. 2019; Yuan et al. 2020; Dolla and Laishram 2020)
16	Foreign aid and NGO's involvement	(Ferronato et al. 2019; Fedotkina et al. 2019; (Yong et al. 2019)

Table 2 Experts' profile and their number

Experts	Number
Environmental engineers	7
Municipality officials	9
Policymakers from the government	6
Supply chain and logistics managers from companies	6
Academia (researchers)	5
Total	**33**

value, i.e., $\mu_c\ (y) = 0$. The constants f and h show the fuzziness of the data. The lesser the distance between the two intervals, the lesser there is fuzziness associated with the data. The ratings associated with the linguistic variables used in this study are shown in Table 3 below.

If there are two triangular numbers such that $\alpha = f, g, h$ and $\beta = f, g, h$, then the distance between the two variables is given with the help of Eq. 3 below.

$$d(\alpha, \beta) = \sqrt{\left(\frac{1}{3}\right)[f - f']^2 + [g - g']^2 + [h - h']^2} \tag{3}$$

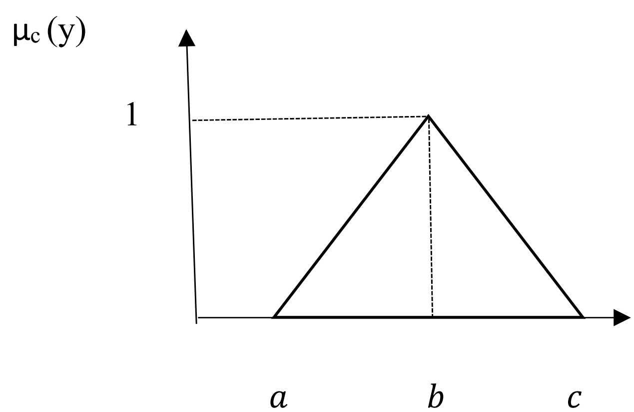

Fig. 2 Triangular numbers

The mathematical equations for dealing with the fuzzy triangular numbers are as follows.

If $A = (x1, y1, z1)$ and $B = (x2, y2, z2)$ are two fuzzy numbers then,

fuzzy addition:

$$A + B = (x1 + x2, y1 + y2, z1 + z2) \tag{4}$$

Table 3 Linguistic variables and their corresponding ratings (source: (Khan, Ali, and Khan, Sustainable hybrid electric vehicle selection in the context of a developing country 2020))

Linguistic variables	Fuzzy number
Very low (VL)	(1, 1, 3)
Low (L)	(1, 3, 5)
Medium (M)	(3, 5, 7)
High (H)	(5, 7, 9)
Very high (VH)	(7, 9, 9)

fuzzy multiplication:

$$A \times B = (x1 \times x2, y1 \times y2, z1 \times z2) \quad (5)$$

fuzzy division:

$$\frac{A}{B} = (\frac{x1}{z2}, \frac{y1}{y2}, \frac{z1}{x2}) \quad (6)$$

After transforming the linguistic variables into their respective fuzzy triangular numbers, the MCDM technique, i.e., fuzzy SWARA, was used to assess the weights of the five criteria. The SWARA technique has been developed by Violeta Keršulienė (Keršuliene et al. 2010). Decision-makers play a pivotal role in evaluating weights to the determined criteria using their expertise and experience. The criteria that receive the significance are ranked first; whereas, the one having the least importance is ranked last. The significance of this method is its simplicity and the benefit of acquiring consistent and robust results (Vafaeipour et al. 2014). The steps associated with the technique are given below (Perçin, An integrated fuzzy SWARA and fuzzy AD approach for outsourcing provider selection, 2019).

Step 1: In the first step, the decision-makers are asked to prioritize the given criteria to the best of their knowledge by using the linguistic variables given in Table 1. Thereafter, the evaluated criteria are sorted in descending order in the expected order of its significance.
Step 2: In this step, the calculations of the average criterion values is carried out by finding t_j:

$$t_j = \frac{\sum_{k=1}^{r} t_{jk}}{r} \quad (7)$$

Where t_{jk} represents the ranking of jth criteria by the kth respondent; also, r shows the number of respondents.

Step 3: In this step, the comparative importance of the sorting criteria is determined based on the expert's opinion which is denoted by S_j.

Step 4: This step involves the calculation of coefficient value k_j.

$$k_j = \begin{cases} 1, j = 1 \\ sj + 1, j > 1 \end{cases} \quad (8)$$

Step 5: This step involves the determination of fuzzy recalculated weights represented by w_j.

$$q_j = \begin{cases} 1, j = 1 \\ \frac{x_{j-1}}{k_j}, j > 1 \end{cases} \quad (9)$$

Step 6: The final step deals with the calculation of fuzzy relative weights of criteria.

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_j} \quad (10)$$

The second step of methodology deals with evaluating the alternatives by using the MCDM technique, i.e., fuzzy VIKOR. Here, the weights of the criteria derived with the help of the fuzzy SWARA methodology were incorporated in the fuzzy VIKOR methodology for further evaluation of the alternatives. The VIKOR methodology has been formulated by (Opricovic and Tzeng 2007). The particular methodology helps in finding a compromised solution along with giving a positive and negative ranking of the alternatives with the help of decision-makers. The steps associated with the technique are as follows.
Step 1: The first step associated with the technique is to gather responses from the decision-makers. The survey form is constructed which is filled by a "q" number of decision-makers, who are asked to evaluate the alternatives (S_k, $k = 1\ldots, m$) based on a given set of criteria (W_i, $I = 1\ldots, n$).
Step 2: The decision-makers allocate weights to the criteria in accordance with the given set of alternatives. For this purpose, the scale given in Table 1 was used.
Step 3: The following Eq. 11 shows the Fuzzy Decision Matrix (FDM) constructed with the help of responses collected from the decision-makers.

$$\text{FDM} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1r} \\ \vdots & \vdots & \ddots & \vdots \\ x_{q1} & x_{q2} & \ldots & x_{qr} \end{bmatrix} \quad (11)$$

For $i = 1, 2, 3\ldots u$ and $j = 1, 2, 3\ldots v$.
Here x_{ij} is the weights allocated to alternative A_i in accordance with the criterion C_j by decision-makers.

Step 4: This step involves the determination of fuzzy best values and fuzzy worst values. The following Eqs. 12 and 13 below give the corresponding values, respectively.

$$f_j^* = \max_i x_{ij} \quad (12)$$

$$f_j^- = \min_i x_{ij} \quad (13)$$

Here $f_j^* = (f_{ja}^*, f_{jb}^*, f_{jc}^*), f_j^- = (f_{ja}^-, f_{jb}^-, f_{jc}^-)$

Where f_j^* refers to fuzzy best values and f_j^- refers to fuzzy worst values.

Step 5: This step involves the determination of S_i and R_i values with the help of Eqs. 14 and 15, respectively.

$$S_i = \sum_{j=1}^{v} w_j * \frac{(f_j^* - x_{ij})}{(f_j^* - f_j^-)} \quad (14)$$

$$R_i = \max_j [w_j * \frac{(f_j^* - x_{ij})}{(f_j^* - f_j^-)} \quad (15)$$

where $(S_i = S_{ia}, S_{ib}, S_{ic})$ and $(R_i = R_{ia}, R_{ib}, R_{ic})$ and w_j refers to the weights of criteria derived from fuzzy SWARA analysis.

Step 6: This step involves the determination of Q_i values with the help of Eq. 16 for all alternatives.

$$Q_i = \frac{v(S_i - S^*)}{(S^- - S^*)} + \frac{(1 - v)(R - R^*)}{(R^- - R^*)} \quad (16)$$

where $(Q_1 = Q_a, Q_b, Q_c)$ and.

$S^* = \min_i S_{ij}, S^- = \max_i S_{ij}$ Similarly

$R^* = \min_i R_{ij}, R^- = \max_i R_{ij}$

Here, S^* indicates maximum group utility, whereas R^* indicates the minimum individual regret of the opponent. Thus, both of these elements help in the determination of the Q_i index. Furthermore, the variable "v" indicates the weight of the strategy of maximum group utility. Hence, if v > 0.5, the decision leans toward the maximum group utility; whereas if v = 0.5, the decision leans toward the minimum individual regret.

Step 7: This step involves the defuzzification of Q values and the ranking. Hence, the triangular fuzzy numbers of Q are defuzzified, and so the alternatives are ranked accordingly. For defuzzification, the geometric mean formula has been used with the help of Eq. 17 below.

$$Q_{\text{defuzzified}} = (Q_a, Q_b, Q_c)^{\frac{1}{3}} \quad (17)$$

Results and discussion

The first step of the analysis dealt with the application of fuzzy SWARA to determine the fuzzy weights of the five distinctive criteria. After the assessment of criteria by experts, the resultant linguistic variables are then transformed into their respective fuzzy numbers using the fuzzy set theory. The first step associated with the fuzzy SWARA methodology was to find the average values of the criteria and sort them in descending order using Eq. 7. Next, the comparative importance of criteria is determined with the help of the expert opinion, which is denoted by S_j. The next step involves the calculation of coefficient value, denoted by k_j, using Eq. 8. Similarly, the fuzzy recalculated weights of criteria are found with the help of Eq. 9. The final step associated with fuzzy SWARA is the calculation of fuzzy relative weights using Eq. 10. The results of the analysis are given with the help of Table 4 below.

As evident from Table 4, environmental criteria (C1) have been given the most significance out of all the criteria, by receiving a final weight of (0.8529, 0.8891, 0.8980). The environment is the most important criterion when it comes to the adoption of CE principles in the waste management sector. Due to the ever-increasing global warming and increase in GHG emissions, environmental sustainability is being considered to be the topmost important factor when it comes to the achievement of UN sustainable development goals and the principles of CE (Adami and Schiavon 2021). It has become even more important in the case of developing countries like Pakistan where poor waste management practices lead to several environmental and health degradation. The biggest example of poor air index quality is Lahore, where people are subjected to several complicated respiratory diseases (Ashraf et al. 2019). To solve the aforementioned problem, the reduction of industrial waste can be the biggest driver toward reduced environmental degradation in the country (Ali et al. 2019a, 2019b, 2019c). The CE approach itself focuses on the adoption of principles that revolve around the use of resources in the best possible manner along with the achievement of goals that revolve around reduced environmental degradation. The aforementioned argument is also advocated by the Ellen Macarthur organization (Haupt and Hellweg 2019).

The next step of the analysis involves the utilization of the weights of criteria obtained from fuzzy SWARA into fuzzy VIKOR for ranking the critical facilitators (alternatives). The first step associated with fuzzy VIKOR is to construct a decision matrix with the help of the responses collected from the experts using Eq. 11. The next step involves the calculation of fuzzy best and worst values using Eqs. 12 and 13, respectively. Subsequently, this is followed by determining the S_i and R_i values using Eqs. 14 and 15, respectively. Whereas, Eq. 16 helps with finding the Q_i values for all the alternatives. The final step involves the defuzzification of the Q_i values using Eq. 17. The results of fuzzy VIKOR containing Q_i values and the ranking are given in Table 5 below.

From Table 5, it is evident that the most critical facilitator for effective waste management in the CE perspective is "standard operating procedures to follow on waste management." There is a significant lacking of a proper plan

Table 4 Results achieved through fuzzy SWARA

Criteria	**Comparative importance of average values S_j**	**Coefficient $Kj = 1 + S_j$**	**Recalculated weight $q_j = \frac{x_{j-1}}{k_j}$**	**Final weight $w_j = \frac{q_j}{\sum_{k=1}^{n} q_j}$**
C1. Environmental	-	(1, 1, 1)	(1, 1, 1)	(0.8529, 0.8891, 0.8980)
C5. Regulatory	(6.515, 8.515, 9)	(7.515, 9.515, 10)	(0.100, 0.105, 0.133)	(0.0853, 0.0934, 0.1195)
C4. Technical	(3.364, 5.364, 7.364)	(4.364, 6.364, 8.364)	(0.012, 0.017, 0.030)	0.0102, 0.0147, 0.0274)
C3. Economic	(2.939, 4.879, 6.879)	(3.939, 5.879, 7.879)	(0.002, 0.000, 0.001)	(0.0013, 0.0025, 0.0070)
C2. Social	(5.788, 7.788, 8.939)	(6.788, 8.788, 9.939)	(0.0002, 0.0003, 0.0011)	(0.0001, 0.0003, 0.0010)

Table 5 Ranked critical facilitators through fuzzy VIKOR

Critical facilitators	Qi values	Rank
Standard operating procedures to follow on waste management	0.0000	1
Environmental management system	0.0228	2
Wide application of digitalization for collecting, sharing, and receiving waste data	0.1614	3
Usage of appropriate methods or technologies to recover value from the waste	0.1891	4
Supportive government policies	0.2130	5
Business models based on circular and sharing economy concepts	0.2136	6
Transfer of waste for reutilization through an industrial symbiosis network	0.2239	7
Incentivizing the procurement of smart waste technologies	0.3332	8
An advanced research and development system	0.3403	9
Educating and spreading awareness campaigns on circular economy and smart waste management practices	0.4250	10
Business opportunities and a potential market for introducing smart waste technologies	0.6765	11
Enhanced citizen participation and green behavior through reward-based systems	0.6852	12
Public–private partnership programs for smart waste technologies adoption	0.7219	13
Smooth and uninterrupted internet facility and a strong cybersecurity system	0.8634	14
Foreign aid and NGO's involvement	0.9028	15
Meeting society's expectations for corporate social responsibility	0.9141	16

for effectively managing solid waste in Pakistan. The contributing reasons for the backwardness of effective waste management are the lack of well-trained professionals, financial resources, political will, and technological innovations. Much of the waste produced is uncollected and the rest of which is collected is dumped or burned openly (Akmal and Jamil, Assessing Health Damages from Improper Disposal of Solid Waste in Metropolitan Islamabad–Rawalpindi, Pakistan 2021). The uncollected waste along with the open dumping and burning of waste, as a result, leads to an increase in GHG emissions and pollution in the environment. Also, the untimely collection of waste in the cities further poses a hindrance toward the treatment or recovery of value from the waste (Azam et al. 2020). However, a more circular-oriented approach here would be to focus more on reducing, reusing, refurbishing, and recycling waste where possible. This as a result will not only limit GHG emissions but will also result in the usage of valuable resources in the best possible manner. If any of the abovementioned objectives are not achievable then the second alternative is to incinerate waste for energy recovery (Devadoss et al. 2021). Solid waste has a considerable potential to produce energy in Pakistan. Around 70% of the imported energy can be avoided through biochemical processes. Whereas, the importing of energy can be completely avoided through the thermochemical processes (Korai, Mahar, and Uqaili, The feasibility of municipal solid waste for energy generation and its existing management practices in Pakistan 2017). The recycling of solid waste can be further increased through energy recovering technologies such as anaerobic digestion, material recovery facilities, and the gasification processes. The particular technology has the potential of giving the highest social, economic and environmental benefits. However, to achieve the aforementioned targets, the government and the municipalities have a huge part to play. The local governments have to make sure, the devised set of operating procedures are followed by both the municipalities and the industries. Here, educating the municipality officials and employees regarding new practices and principles is very important. The specific kind of training can be achieved through giving workshops to these workers, along with educating them on smart waste technologies and new recycling technologies.

The second most critical facilitator for effective waste management in Pakistan is “environmental management systems.” Industries in any country are responsible for most of the production of toxic and nontoxic waste. Thus, to effectively manage this waste, the industries in Pakistan needs to primarily focus on adopting business models, based on sharing and CE concepts. To minimize waste in the production phase, the industries have to adopt the principles of lean manufacturing. Moreover, a proper analysis of the overall production process can be carried out through performing life cycle assessments. Hence, this is a result would help the industries to achieve sustainable growth along with achieving the CSR targets. The waste produced in the production process can be transferred to other industries for its further usage through an industrial symbiotic network. The waste that is produced in the downstream part of the supply chain can be managed through a reverse logistics infrastructure. For tracking the waste, the usage of RFID tags can be really helpful. The integration of RFID tags, alongside GPS, GPRS, and GIS technologies has proven to be very successful in overall waste collection, bin, and truck monitoring in Malaysia (Hannan et al. 2011). Moreover, the implementation and adoption of certifications like ISO 14001 can further help these organizations to fulfill the CSR objectives alongside the achievement of sustainable development. Here, the government can play its part by making sure these industries are following the right practices by devising supporting policies and legislation. When it comes to the manufacturing industry sector of Pakistan, the organization’s culture and control system contribute significantly toward environmental performance (Ong et al. 2019). This in a way would help Pakistan’s industries not only to achieve their corporate social responsibility or UN sustainable development goals but would also help these organizations in growing financially. However, sustainable waste management practices can only be followed by industries in Pakistan, if the governing and regulating bodies in the country are more effective in their law-making processes and also ensure their effective application. Unfortunately, the country lacks in both departments (Khan et al. 2021a, 2021b).

From Table 5, the experts ranked the “wide application of digitalization for collecting, sharing, and receiving waste data” to be the third most critical facilitator for effective waste management in the context of CE. The biggest problem associated with developing countries like Pakistan is the lack of availability of waste data associated with the waste generated in the country (Masood et al. 2014). Access to this waste data for all the stakeholders is very necessary for its timely collection and treatment purposes. The aforementioned objective can be attained through the adoption and application of IoT and ICT technologies. The waste data can be made available to all the stakeholders through a cloud-based computing system, helping them to monitor and manage waste data accordingly (Pardini et al. 2020). Moreover, the usage of GIS technology to track and collect waste can be helpful for municipality officials in the timely collection of waste. The usage of the particular technology for efficient monitoring and effective vehicle activity and waste collection has already been proposed to be very beneficial for one of the biggest provinces of Pakistan, i.e., Punjab (Nasir et al. 2017). A study carried out in the case of twin cities, i.e., Islamabad and Rawalpindi, suggests that the application of the GIS technology has the potential to reduce travel time, which was reduced by up to 18% for Islamabad and 9% for Rawalpindi. The collection time of the waste was also reduced accordingly (Hina et al. 2020). A lot of financial resources annually go to the collection of waste from the municipal waste bins. It has been seen that adopting IoT-based technologies particularly the use of smart sensors and smart bins can reduce the overall cost of waste collection by 30–40% (Cassady 2018). It has been studied that the adoption of IoT-based technologies in Pakistan can prove to be very beneficial for the timely collection and treatment of household waste and also waste on a district level (Shaukat et al. 2019). Moreover, adopting smart technologies has a significant potential of achieving social, environmental, and economic targets in waste management and is a driving force toward the achievement of CE principles (Lu et al. 2020; Alcayaga et al. 2019).

All of the above can be made possible through a collaborative framework between all the stakeholders. Without an integrated framework, the transition toward smart management technologies cannot be practical. Thus, the government needs to come up with supporting legislation that is in line with the sharing and CE concepts. The governing bodies need to focus on allocating more budget for waste management. Also, focusing on capacity building of the municipality employees and workers is very essential. The potential investment in waste management and the building of smart cities through the China–Pakistan Economic Corridor project (CPEC) can prove to be very successful toward the adoption of new smart waste technologies (Korai et al. 2020). The public needs to adopt green behavior and should properly dump their waste. Here, incentivizing the public on green practices can be very helpful. Finally, a country like Pakistan is already moving toward the building of smart cities in the cities of Lahore, Quetta, and Multan cities (Farooq 2018). Hence, there is going to be an increasing demand for new smart waste technologies in the country. Thus, this is another enabler for the successful adoption of smart waste management technologies in the country along with bringing potential business opportunities for the people.

Conclusion

With each passing year, solid waste management is becoming more complex and difficult to manage because of the increase in the world population. To engage in a more sustainable waste management approach, most countries around the world are moving toward the adoption of CE principles. The aim of this paradigm shift is to engage people and industries into becoming more responsible by reducing, reusing, and recycling waste. However, the transition toward sustainable waste management practices in the accordance with the CE paradigm is not an easy task. In particular, developing countries like Pakistan faces more challenges in their waste management sector because of their meager resources and relatively weak infrastructure as compared to those in developing countries. However, this could be made possible if the country engages in being more responsible in terms of formulating new policies that go in accordance with the CE approach. The intricate nature and the involvement of several whole processes during waste management can be better tackled by adopting new smart waste technologies. However, to achieve this goal, the country has to devise supporting policies and strategies to aid this transition. To solve this problem, the aim of this is to devise a facilitating framework by which Pakistan can adopt sustainable waste management practices in accordance with the CE approach through the adoption of smart waste management technologies. For this purpose, the study goes through an extensive literature review and identifies 16 critical facilitators with the help of experts for the successful transition toward the new paradigm. These 16 critical facilitators are then ranked based on five distinctive criteria that include environmental, social, economic, technical, and regulatory perspectives. To evaluate the determined critical facilitators, the study uses a hybrid MCDM approach. For the determination of weights of criteria, the fuzzy SWARA approach is used. Whereas, the fuzzy VIKOR approach is used for ranking the critical facilitators. The fuzzy approach used in both cases is to avoid any type of uncertainty during the decision-making process.

Through the application of fuzzy SWARA, the experts prioritized "environmental" criteria to be the most important factor in assessing the critical facilitators. Among the 16 critical facilitators, the experts advocated that Pakistan in the first phase should focus on devising policies and legislation that better addresses the mismanagement of waste in the country. The newly developed policies should be more in line with the principles of CE. The experts on a second priority advocate the adoption of environmental management systems by the industries as the second most critical facilitator toward sustainable waste management practices in the country. In the third phase, the country should move toward the adoption of smart waste technologies for collecting, sharing, and receiving waste data accordingly.

The study suggests that a collaborative and synergetic framework between the municipalities, public, and the industries is very important for a smooth transition toward the principles of CE and the adoption of smart waste technologies. In essence, supporting policies from the government in this context is also very essential. Furthermore, when it comes to CE, waste minimization and the usage of sustainable technologies to recover value from the waste is also very important. Further studies in this context should focus more on the feasibility of the showcased model in this study by performing a life cycle assessment and cost–benefit analysis of adopting smart waste technologies in Pakistan.

Author contribution All authors contributed to every part of the manuscript. Feroz Khan contributed to the data collection and analysis part, while Yousaf Ali drafted the whole document.

Availability of data and materials Data will be available upon request.

Declarations

Ethics approval We declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication I, the undersigned, give my consent for the publication of identifiable details, which can include data, figures and tables, and details within the text ("Material") to be published in this article.

Conflict of interest The authors declare no competing interests.

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