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Optimizing Construction and Demolition Waste Management Strategies in Libya: A FUCOM-EDAS Multi-Criteria Decision-Making Approach

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Abstract: Waste management has emerged as a critical environmental challenge globally, particularly in the context of rapid urbanization, which has significantly increased waste generation. Effective strategies for handling construction and demolition (C&D) waste are essential to mitigate environmental impacts. In Libya, the aftermath of the 2011 conflict and subsequent instability has led to extensive destruction of public and private infrastructure. As reconstruction efforts accelerate, the absence of a structured framework for C&D waste management remains a pressing concern, with current practices predominantly involving disposal in open dumps alongside municipal solid waste. This study employs the Full Consistency Method (FUCOM) to determine the relative importance of key criteria and the Evaluation Based on Distance from Average Solution (EDAS) method to assess alternative waste management strategies. The findings indicate that investment cost is the most influential criterion, followed by social acceptance. Among the evaluated strategies, landfilling emerged as the most suitable alternative. To ensure the robustness of the results, a sensitivity analysis was conducted by varying the weight distributions across seven additional scenarios, consistently reaffirming the superiority of landfilling. Furthermore, a comparative analysis was performed using three other Multi-Criteria Decision-Making (MCDM) models—COmbinative Distance-based ASsessment (CODAS), VIKOR, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)—each corroborating the ranking of landfilling as the optimal strategy. The insights derived from this study underscore the necessity for policymakers to integrate cost-effective and socially acceptable solutions into Libya's C&D waste management framework to support sustainable reconstruction efforts.

Keywords: Multi-criteria decision-making (MCDM); Construction and demolition (C&D) waste; Full consistency method (FUCOM); Evaluation based on distance from average solution (EDAS); Waste management strategies; Libya

1 Introduction

Generally, C&D debris is defined as the waste materials generated from construction, demolition and renovation of structures such as buildings, roads, bridges, dams, utility plants and other civil engineering structures. C&D debris typically contains concrete, metals, bricks, glass, plastics, wood, gypsum, soil, asphalt and salvaged building components [1].

Human consumption of natural resources has tremendously increased in the last few decades. The usage of raw material in construction has been increasing all over the globe in a way that is superior to any other industry, which leads to severe environmental impacts [2]. Approximately one-third of the waste generated in the European Union is C&D waste [3]. Several researches investigate that C&D waste has reached 30–40% of the total solid waste because of the large-scale C&D activities resulting from the accelerated urbanization and city rebuilding [4]. Thus, many techniques have been developed to either reduce the use or increase the recycle of materials in order to minimize negative impacts on the environment. Many countries realized the necessity of adopting strategic management plans to lower the enormous amounts of waste. Tremendous efforts have been made to further improve the process of C&D waste recycling.

Nevertheless, studies from various countries have revealed a lack of interest in implementing C&D waste management effectively due to a wide range of reasons. The main barriers to C&D waste management, as identified in previous studies, are illustrated as follows [5]:

1. Lack of public awareness for waste management problems,
2. Absence of adequate treatment and disposal facilities,
3. Lack of incentives from regulatory authorities,
4. Absence of regulatory control,
5. Low disposal costs for sending materials to landfills,
6. Low costs of building materials.

In many countries, C&D waste is usually dumped in landfills with a small amount being recycled. Recycling has been proven to be challenging in most developing countries because the amount of waste generated is not well documented. Therefore, economic viability of recycling and awareness about the many benefits of C&D waste recycling are limited [6].

Arab countries still mostly treat the demolition and construction waste by dumping it in landfills. And given that it produces large amounts of construction waste, this causes various environmental damages. For instance, in Egypt, the daily quantity of C&D waste has been estimated as 4.5 million tonnes annually [7]. C&D waste almost represents 44% of the total solid waste generated in 2010. Regardless of everyday problems that include institutional deficiencies, inadequate legislation, and resource constraints, open dumping is still well thought out as the most popular method of solid waste disposal [8]. Demolition activities are carried out by conventional methods. Advanced demolition techniques, i.e., using explosive materials, are not commonly used [7]. Also, C&D debris represents a major component of solid waste; more than 90% of it is landfilled in Kuwait. Numerous intensive measures to encourage construction materials reduction and reuse in Kuwait have been unable to significantly raise reutilization rates. As a result, the number of new landfill sites designated for C&D waste is increasing, as well as those uncontrolled or unregulated sites. The total C&D waste production in Kuwait is around 1.6 million tonnes/year [9]. Additionally, Qatar has been undergoing a major program of building infrastructure development in recent years, resulting in the generation of enormous quantities of construction, demolition, and excavation wastes. This accounts for almost 75% of all waste generation in Qatar. The material is dumped at a site in the desert, causing degradation of a large area. Some of the cleaner excavation waste is being processed as recycled aggregates, but this only treats about 10% of the total waste stream [10]. Annual solid waste in the country varies around 10 million tonnes, making Qatar one of the highest waste-generating countries per capita [11].

The main objective of this study is to assess different C&D waste management strategies in Libya using FUCOM-EDAS model. In spite of the fact that relevant data is moderately small, however, they provide significant knowledge for understanding the status of C&D waste management in the country. Furthermore, alternative scenarios were developed to select the appropriate management strategy. The study additionally aims to shed light on the current situation of solid waste, methods of waste disposal, and regulated legislations of waste management in Libya. As far as we know, there is no previous study in Libya regards the selection of the most appropriate strategy for managing demolition and construction waste.

2 C&D Waste in Libya

Moving on to Libya, which is a country located in the Maghreb region in North Africa between longitude 9°-25° east and latitude 18°-33° north with an area of 1.8 million square kilometres. Libya has nearly 6.8 million people with a 1.4% natural increase per year. Most of the Libyan population lives in cities on the coast. Libya is bounded on the north by the Mediterranean Sea, on the east by Egypt, on the southeast by Sudan, on the south by Chad and Niger, on the west by Algeria, and on the northwest by Tunisia. The total land boundary length is 4,348 km, and the coastline is 1,770 km. About 90% of the Libyan land is desert or semi-desert with a Mediterranean climate along the coast and extreme desert on the interior. The land use includes about 8.8% agricultural land, 0.1% forests, and 91.1% other land.

The Libyan economy depends mostly on oil and gas export revenues. Oil was first discovered in Libya in 1956. The World Bank defines Libya as an 'Upper Middle Income Economy', along with only seven other African countries [12]. The economy has struggled in Libya since 2014 due to security and political instability, which caused a decline in oil production and a significant loss in the foreign exchange rate of the Libyan dinar. Libya has an oil reserve of 47.1 billion barrels, as reported in 2012, which is the largest endowment in Africa and among the ten largest worldwide [13].

2.1 Current Situation of C&D Waste in Libya

C&D waste, in Libya, can be produced by different sources and causes at different stages of the construction project. Part of these causes would result from structure design errors, and others could be modifications for ongoing building trends. However, other reasons have also contributed to producing C&D waste, namely Libyan uprisings and fights against IS. For instance, in Misurata city, more than 6,000 buildings have been destroyed by the war, and their damage varies from complete destruction to minor or moderate damage. So, the demolition and the refurbishment of these buildings produced C&D waste excessively. Figure 1 shows construction waste and destroyed houses in Misurata [14].

Solid waste collection, including C&D waste, is the responsibility of municipalities and private sectors. They collect construction waste using trucks and dump it out of cities. Currently, open landfilling is the most common method of C&D waste disposal, for approximately 1.2 Mt of waste per year in Libya [15]. In addition, the management of this massive amount of waste is ineffective. Although there are many plans to deal with this conundrum, especially in the main cities of the country, they only remain plans without implementation [16].

Moreover, poor solid waste utilisation is a huge cause for concern in the national community. Municipalities face great challenges to respond to the basic requirements that directly affect people's lives, such as effective waste collection or proper disposal. The direct reason for this is the lack of sufficient means to collect the waste, such as collection trucks and human resources [17]. The problem has existed in Libya since before the 2011 uprising, but it has now increased further and has become a major burden with serious implications for public health and the environment.

The absence of regulatory control by local authorities in Libya has led to innumerable violations committed by contractors and citizens. Construction wastes are basically left at the work sites for a long time and often disposed of at undesignated sites. Inappropriate disposal places include roadsides, agricultural lands, and valleys where debris blocks water flow in winter. C&D wastes are randomly dumped and accumulated in harmful locations to the environment using private trucks. Moreover, low prices of construction materials, the absence of strict law enforcement measures for unlicensed contractors and unpermitted constructions are key factors that certainly have negative effects.

2.2 Challenges to the Utilization of CW Management

Maintaining a solid management system of C&D waste has been a great challenge for most of the world's countries. Some countries have made considerable achievements; however, there are still many aspects that are not properly handled [18]. Some of the factors that made countries struggle to cope are country regulations, the economy, the role of stakeholders, and construction parameters. Findings of many recent studies divided the C&D waste management challenges into two categories. The first category is called "off-site challenges," which include issues outside of the C&D waste sites. The second category is called "on-site challenges," which include issues that take place on C&D waste sites [18]. Libya, like most of its neighbouring countries, is still off track on dealing with C&D waste management. According to Etriki, there are significant missing components in the Libyan management framework [19].

Local government is in urgent need of encouraging public awareness in contractors' communities and enforcing obeying rules and regulations. In addition, recycling activities have to be supported in order to provide access to disposal facilities so that it helps investors to improve the waste management process in the country. However, mandatory inspection is granted by law during the construction process to ensure the proper application of the building code.

Figure 1. Destruction on Misurata [14]

2.3 Estimates of C&D Waste in Libya

Implementation of proper techniques to estimate C&D waste quantities is a key factor for an effective management system [20]. The amount of C&D waste generated from construction and renovation activities in urban areas is usually huge. They also require practical strategies to control waste within the local policy. In Europe, Directive 2008/98/EC emphasised the need to quantify waste streams and improve the material recycling efficiency of C&D waste in the European Union [21]. Wu et al. [22] in his review research, classified the C&D waste quantification methods into six categories that consist of: Site visit method, generation rate calculation method, lifetime analysis method, classification system accumulation method, variables modelling method and other particular methods.

In Libya, there is a lack of data for C&D waste quantities due to the absence of laws that enforce citizens to record and report measurements of C&D waste [16]. The country of Libya has suffered from mass destruction of infrastructure and facilities in different cities following the 2011 conflict and the ongoing crisis since 2014. In hope for a bright future, Libya has both human and financial resources to reunite and move forward to a modern country. As there are limited data available for the C&D waste estimation in Libya, Abukersh [23], in his research, indicated that the annual C&D waste produced in Libya is estimated in the range of 400-450 kg per capita.

2.4 The Impacts of CW on Environment

For the last decade in Libya, the amount of construction waste has gradually increased due to the construction activities and the conflict on the ground. This growth, in parallel with the decreased landfill area, has negatively affected the environment, mainly in urban areas. Additionally, Libya is an example of an African country that has faced difficulties with a significant rise in the quantity of C&D waste due to a fast-increasing population and alterations in consumption patterns with economic development. Poor planning and environmental management, as well as an increase in population and a lack of tools and equipment used to collect and transport waste to landfills, have led to urban pollution [24]. In addition, some of these landfills are located directly on the coast; consequently, dumping C&D waste in these natural areas would lead to water pollution. Based on that, Libya has been ranked 123rd out of 142 countries in terms of environmental degradation [25].

On the other hand, the increase of C&D waste was going side by side with the increase of stone pit industries. The number of stone pits has dramatically spiked. For instance, in Bani Walid, a city located in northwest of Libya, the area that had been used for aggregate industry in 1990 was about 18.9 hectares. By the year 2018, the area had extended to 627.8 hectares. From an environmental perspective, this expansion on stone pits has negatively affected the environment, namely the vegetation and wildlife. Figure 2 below shows the expansion of stone pits from 1990 to 2018 [26].

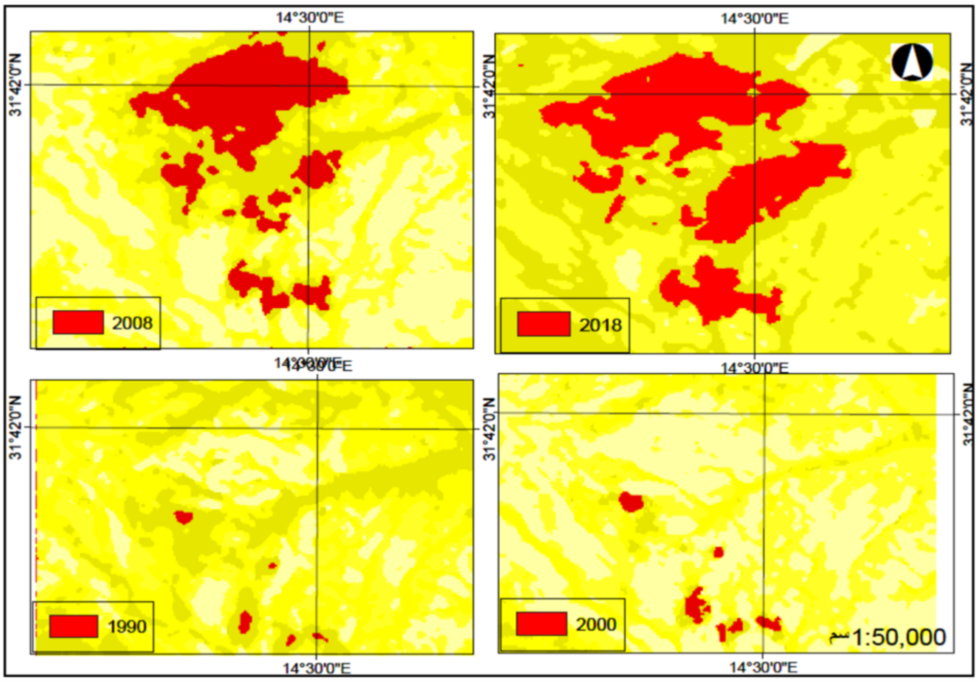

Figure 2. Expansion of stone pits in Wadi Almardom [26]

2.5 Corresponding Legislations

Libya was one of the first Arab countries to legislate laws to protect the environment. In 1958, a series of laws and decrees were implemented to ensure environmental protection. They dealt with the treatment of risks of environmental pollution, along with the imposition of severe penalties on violation of the provisions of such laws [27]. Law No. 5 (1969) on the planning and organisation of towns and villages and its amendments implemented different legislative rules. In particular, part 5, which stated the provisions relating to the establishment, management, and maintenance of public utilities such as water and sewage. Law No. (130) of 1973 addressed the local administration system, bringing services closer to the citizens and involving them in the management of local facilities related to the affairs of their lives within the framework of a decentralised system [28].

It is worth noting here that there are many governmental institutions that are related to the field of the environment, such as the Environment General Authority (EGA) and the General Water Authority (GWA). EGA is the main institution concerned with the environment in Libya. It was established in 1982 as a technical centre for environmental protection and then upgraded into its current form in the year 2000.

In a like manner, Libya has worked with the international community by signing a group of conventions and agreements. Table 1 shows a list of conventions signed and ratified by Libya internationally.

Table 1. List of conventions signed and ratified by Libyan authorities [29]

Convention	Date of Ratification	Reporting Obligation
The Ramsar Convention on the preservation of wetlands	1971	Information Sheet on Ramsar Wetlands (RIS)
The Convention on Biological Diversity	1992	National report on implementation of the Convention
The Cartagena Protocol on Biosafety	2000	National report
The Convention on International Trade in Endangered species of wild fauna and flora.	1973	Annual report on CITES trade and biannual report on legislation
The Vienna Convention and Montreal Protocol to protect the ozone layer	2014	Annual ODS report
The Basel Convention on the Control of Hazardous Wastes and their transfer across the border Hazardous Wastes and their transfer across the border	1989	Yearly report to the Convention
The United Nations Convention to Combat Desertification	1995	Report on implementation
Bamako convention on the ban of the import into Africa and the control of transboundary movement and management of hazardous wastes within Africa	1991	Report on implementation

Despite the facts previously mentioned, there is still a gap between the legislation and the enforcement on the ground. Most municipalities are struggling to spread awareness among people. They also face problems in achieving positive steps in order to strengthen the linkages between organisations and projects devoted to environmental sustainability.

3 Methodology

Figure 3 illustrates the methodology used in this research, where the weights of the criteria were determined using the FUCOM method. After that, alternatives were compared using the EDAS technique. Three methods were used to compare alternatives, which are VIKOR, TOPSIS, and CODAS.

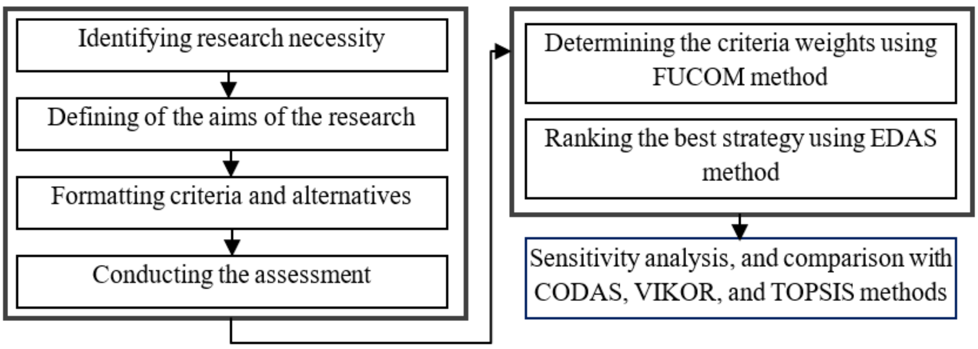

Figure 3. Methodology of the research

3.1 FUCOM Method

Recently, MCDM problems have received more attention from researchers, both in terms of developing new methods and MCDM applications [30–35]. The FUCOM is a new model that uses the pairwise comparison concept. The validation of results can be done through the deviation from maximum consistency [36]. It is a model that, to some extent, eliminates the stated deficiencies of the Best-Worst Method (BWM) and Analytic Hierarchy Process (AHP) models. Compared to AHP, it needs a fewer number of pairwise comparisons of criteria (only n-1 comparisons) [37, 38]. It is also flexible in terms of using a different scale depending on the expert's preference. Like other subjective models for determining the criteria's weights [39], the FUCOM model also has a subjective effect on the final values of the weights of criteria. This can be explained by the fact that the decision-makers in the FUCOM model rank the criteria according to their personal preferences and then perform the pairwise comparisons according to the established ranking of the criteria. However, compared to other methods, it can be said that FUCOM gave minor deviations from optimal values for the obtained weights of the criteria [40–42]. One of the advantages of the FUCOM method, compared to some other models that use pairwise comparisons, is that it eliminates the problem of redundancy in the pairwise comparisons of criteria [43, 44]. FUCOM has been used in many applications, such as forklift selection [45], ranking the airlines [46], service quality measurements [47], occupational safety and health climate [48], service quality of rail transport [40], and supplier selection [49, 50]. Figure 4 shows the model steps.

Assume that there are n evaluation criteria in a multi-criteria model that are designated as w_j, j= 1,2, ..., n, and that their weight coefficients need to be determined.

Restriction 1 could be written as $w_k/w_{k+1} = \varphi_{k/(k+1)}$. Also, Restriction 2 could be written as $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

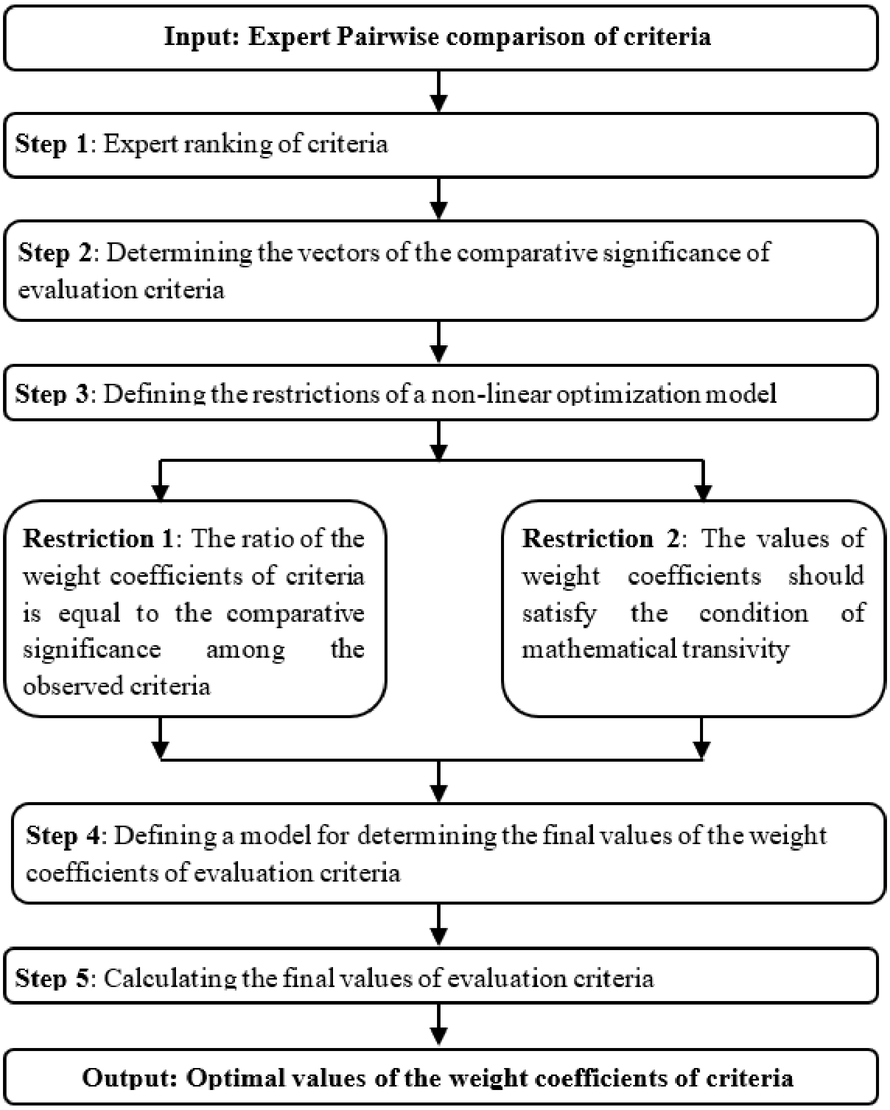

Figure 4. FUCOM method steps

The model for determining the final values of the weight coefficients of evaluation criteria could be written as:

$$
\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq \chi, \forall j \\
&\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j \\
&\sum_{j=1}^{n} w_j = 1, \forall j \\
&w_j \geq 0, \forall j
\end{aligned} \tag{1}
$$

3.2 EDAS Method

The EDAS method is a robust MCDM approach designed to assess alternatives based on their relative closeness to an average solution. Unlike traditional methods that rely solely on ideal or anti-ideal comparisons, EDAS evaluates each alternative's performance through two primary measures: Positive Distance from Average (PDA) and Negative Distance from Average (NDA) [51]. These measures account for how much better or worse an alternative performs compared to the average, offering a balanced perspective. With its simplicity, computational efficiency, and ability to handle diverse criteria, EDAS has been widely adopted in decision-making scenarios, ranging from supplier selection to project prioritization [52, 53]. The following are the steps involved in the EDAS method.

Step 1: Choose the most important criteria that impact decision-making on the studied problem.

Step 2: Construct the decision-making matrix (X), shown as follows:

$$
X = [x_{ij}]_{nxm} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ x_{31} & x_{32} & \dots & x_{3m} \\ & \dots & \dots & \dots \end{bmatrix} \tag{2}
$$

where, X_{ij} denotes the performance value of the i^{th} alternative on the j^{th} criterion.

Step 3: Determine the average solution according to all criteria, as follows:

$$
AV = [AV_j]_{1xm} \tag{3}
$$

$$
AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{4}
$$

Step 4: Calculate the PDA and NDA matrixes according to the type of criteria (benefit and cost), shown as follows:

$$
PDA = [PDA_{ij}]_{nxm} \tag{5}
$$

$$
NDA = [NDA_{ij}]_{nxm} \tag{6}
$$

If the j^{th} criterion is beneficial,

$$
PDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \tag{7}
$$

$$
NDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \tag{8}
$$

and if the j^{th} criterion is non-beneficial,

$$PDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \tag{9}$$

$$NDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \tag{10}$$

where, PDA_{ij} and NDA_{ij} denote the positive and negative distance of the i^{th} alternative from the average solution in terms of the j^{th} criterion, respectively.

Step 5: Determine the weighted sum of PDA and NDA for all alternatives, shown as follows:

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij} \tag{11}$$

$$SN_i = \sum_{j=1}^{m} w_j NDA_{ij} \tag{12}$$

where, w_j is the weight of the jth criterion.

Step 6: Normalize the values of SP and SN for all alternatives, shown as follows:

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \tag{13}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i(SN_i)} \tag{14}$$

Step 7: Calculate the appraisal score (AS) for all alternatives, shown as follows:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{15}$$

where, $0 \leq AS_i \leq 1$.

Step 8: Rank the alternatives according to the decreasing values of AS. The alternative with the highest AS is the best choice among the candidate alternatives.

4 Case Study

Waste management has become an important problem during the last decades, mostly due to the complexity of waste streams and the steady increase in produced volumes. Given the importance of the topic, many studies have researched the applications of MCDM in the field of C&D waste management, whether in terms of selecting the best technology or the site selection for landfills. Usually, integration of environmental, economic, and social criteria is used, such as when they are appropriate to the case being studied. Just as these criteria may differ from one region to another, their importance will often also change according to the study case.

The aim of this research is to determine the most suitable C&D waste treatment strategy in Libya. The suggested strategies are: Landfilling (mentioned as A1 in the calculations), Direct on-site recovery of individual recyclable material/transfer of non-recyclable materials to landfill (A2), Centralized on-site recovery in a mobile recycling center/ transfer of non-recyclable materials to landfill (A3), Landscaping works (A4), and Transfer mixed recyclable materials to recycling center/transfer of non-recyclable materials to landfill (A5).

A set of criteria was selected based on literature review and through the discussion with some experts in the area. The selected criteria include economic, technical, environmental and social criteria, and these criteria are as follows: Social acceptance (mentioned as C_1 in the calculations), Possibilities of new job positions (C_2), Investment cost (C_3), Production of solid outcast (C_4), Level of possible environmental repercussions (C_5), Adaptability in the local conditions (C_6), and Air emissions (C_7). The first, second, and sixth criteria are positive criteria, the rest are negative criteria. Criteria weights will first be calculated using the FUCOM method. The steps will be explained in some detail.

Step 1. In this step, the experts rank the criteria in descending order of importance: $C_3 > C_4 > C_5 > C_2 > C_6 > C_1 > C_7$.

Step 2. In the second step, pairwise comparison of criteria is carried out by the experts. The comparison was made based on the scale [1, 9] with respect to the first-ranked C_3 criterion. Thus, the priorities of the criteria ( ) for all of the criteria ranked in Step 1 were obtained (Table 2).

Next, we calculate the comparative priorities as below:

$$\varphi_{C_3/C_4} = 1.5/1.0 = 1.5, \varphi_{C_4/C_5} = 2.0/1.5 = 1.33, \varphi_{C_5/C_2} = 2.8/2.0 = 1.4$$

$$\varphi_{C_2/C_6} = 3.0/2.8 = 1.07, \varphi_{C_6/C_1} = 5.0/3.0 = 1.67, \varphi_{C_1/C_7} = 6.0/5.0 = 1.2$$

Step 3. The following two restrictions must be satisfied:

a) Ensure that the final values of the coefficients match with Eq. (3), i.e.:

$$\frac{w_3}{w_4} = 1.5, \frac{w_4}{w_5} = 1.33, \frac{w_5}{w_2} = 1.4, \frac{w_2}{w_6} = 1.07, \frac{w_6}{w_1} = 1.67, \frac{w_1}{w_7} = 1.2$$

The final model for determining the coefficients could be defined as:

$$\min \chi$$
$$\text{s.t} \begin{cases} \left|\frac{\omega_3}{\omega_4} - 1,5\right| \le \chi, \left|\frac{\omega_4}{\omega_5} - 1,33\right| \le \chi, \left|\frac{\omega_5}{\omega_2} - 1,4\right| \le \chi \\ \left|\frac{\omega_2}{\omega_6} - 1,06\right| \le \chi, \left|\frac{\omega_6}{\omega_1} - 1.67\right| \le \chi, \left|\frac{\omega_1}{\omega_7} - 1,2\right| \le \chi \\ \left|\frac{\omega_3}{\omega_5} - 2,0\right| \le \chi, \left|\frac{\omega_4}{\omega_2} - 1,87\right| \le \chi, \left|\frac{\omega_5}{\omega_6} - 1,5\right| \le \chi \\ \left|\frac{\omega_2}{\omega_1} - 1,79\right| \le \chi, \left|\frac{\omega_6}{\omega_7} - 2,0\right| \le \chi \\ \sum_{j=1}^{7} \omega_j = 1, \omega_j \ge 0, \forall j \end{cases} \tag{16}$$

The final values of the weight coefficients and DFC of the results are obtained by solving this model. The obtained weights of the criteria are shown in Figure 5. The model is solved using the MS excel solver. From the obtained results, it can be concluded that the most important criterion is C_3, followed by the criterion C_1.

After the weights of the various criteria have been calculated, the proposed strategies are now evaluated using the EDAS method. In the following steps, the calculation method will be explained in detail.

Table 2. Priorities of criteria

Criteria	**C$_3$**	**C$_4$**	**C$_5$**	**C$_2$**	**C$_6$**	**C$_1$**	**C$_7$**
$\varpi_{C_{j(k)}}$	1.0	1.5	2.0	2.8	3.0	5.0	6.0

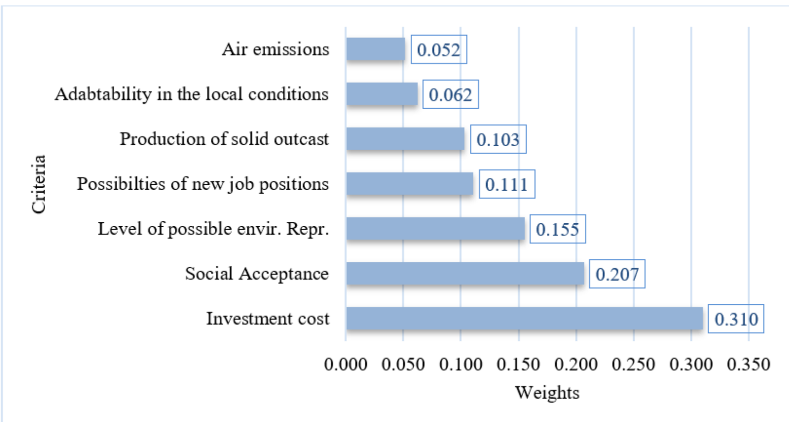

Figure 5. The value of decision criteria

Initial evaluation matrix is prepared as follows:

$$X = \begin{bmatrix} 3 & 2 & 8 & 2 & 8 & 8 & 2 \\ 3 & 6 & 3 & 6 & 4 & 5 & 7 \\ 4 & 5 & 3 & 7 & 4 & 6 & 7 \\ 5 & 5 & 6 & 5 & 7 & 4 & 3 \\ 8 & 7 & 2 & 1 & 1 & 3 & 8 \end{bmatrix}$$

Using Eq. (4), the average criteria weights are calculated as follows:

$$AV = \begin{bmatrix} 4.6 \\ 5.0 \\ 4.4 \\ 4.2 \\ 4.8 \\ 5.2 \\ 5.4 \end{bmatrix}$$

Positive and negative distances are then calculated using Eqs. (7)-(10) for different strategies:

$$PDA = \begin{bmatrix} 0.000 & 0.000 & 0.000 & 0.524 & 0.000 & 0.538 & 0.630 \\ 0.000 & 0.200 & 0.318 & 0.000 & 0.167 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.318 & 0.000 & 0.167 & 0.154 & 0.000 \\ 0.087 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.444 \\ 0.739 & 0.400 & 0.545 & 0.762 & 0.792 & 0.000 & 0.000 \end{bmatrix}$$

$$NDA = \begin{bmatrix} 0.348 & 0.600 & 0.818 & 0.000 & 0.667 & 0.000 & 0.000 \\ 0.348 & 0.000 & 0.000 & 0.429 & 0.000 & 0.038 & 0.296 \\ 0.130 & 0.000 & 0.000 & 0.667 & 0.000 & 0.000 & 0.296 \\ 0.000 & 0.000 & 0.364 & 0.190 & 0.458 & 0.231 & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.423 & 0.481 \end{bmatrix}$$

Finally, the AS values for all proposed strategies are obtained using Eq. (15) as follows:

$$AS_1 = \frac{1}{2}(0.446 + 0.000) = 0.223$$

$$AS_2 = \frac{1}{2}(1.000 + 0.843) = 0.922$$

$$AS_3 = \frac{1}{2}(0.816 + 0.782) = 0.799$$

$$AS_4 = \frac{1}{2}(0.015 + 0.596) = 0.305$$

$$AS_5 = \frac{1}{2}(2.543 + 1.000) = 1.771$$

By arranging the AS values obtained in descending order, the ranking of the proposed strategies can be obtained as follows: A5>A2>A3>A4>A1.

After the best strategy has been determined, the effect of changing the weights of different criteria on the ranking of the proposed strategies will be examined in this step. The change will be made for each criterion separately by changing the weight of a targeted criterion and giving equal weights to the rest of the criteria. Weights can be calculated from the following equation [54]:

$$wj = \frac{1 - w_g}{m - 1} j \in \{1, 2, \ldots m\} \text{ and } j \neq g$$

Figure 6 shows the results obtained from the sensitivity analysis. There are eight scenarios in this figure, the base model in addition to seven other scenarios that resulted from changing weights of each criterion. It can be seen that strategy A5 is the best strategy in all cases, and scenario A2 is second (except the scenario in which a higher C_4 weight was given). In general, the result obtained in the base model can be said to be mostly stable and not significantly affected by a change in the weights of the criteria.

Additionally, different methods of MCDM are applied to validate the results. The applied methods are: CODAS, TOPSIS, and VIKOR. Table 3 shows the values obtained in each method and the ranking of each of the alternatives.

We can notice that from Figure 7, which shows the ranking of alternatives using the four methods, the obtained rankings changed only between alternatives A1 and A4 for the CODAS and EDAS methods.

Figure 8 and Figure 9 present the Spearman Correlation Coefficients (SCC) and Wojciech Sałabun (WS) correlation coefficients, showcasing the rankings derived from comparative analysis using various methods, along with sensitivity analysis results based on adjustments to criteria weights. The SCC results reveal a perfect correlation (SCC=1.000) for methods such as MARCOS and TOPSIS, while CODAS exhibits a slightly lower SCC value of 0.900, indicating minimal variation. Overall, the rankings across all methods show a strong correlation, with the average SCC and WS values being almost identical, demonstrating the robustness and consistency of the methods in evaluating alternatives.

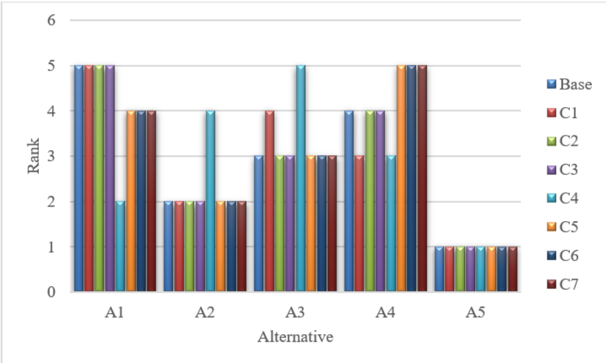

Figure 6. Sensitivity analysis

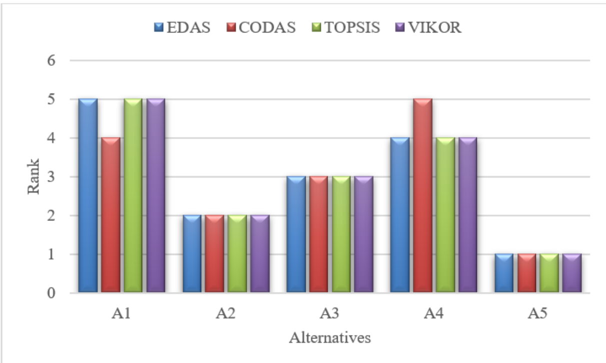

Figure 7. Ranking of different alternatives

Table 3. Ranking of different alternatives

Alternative/ Measure	CODAS		TOPSIS		VIKOR *	
Hi	Rank	Ci	Rank	Qi	Rank	
A1	-0.543	4	0.231	5	1.114	5
A2	-0.173	2	0.679	2	0.376	2
A3	-0.185	3	0.655	3	0.433	3
A4	-0.874	5	0.327	4	0.815	4
A5	1.775	1	0.856	1	0.114	1

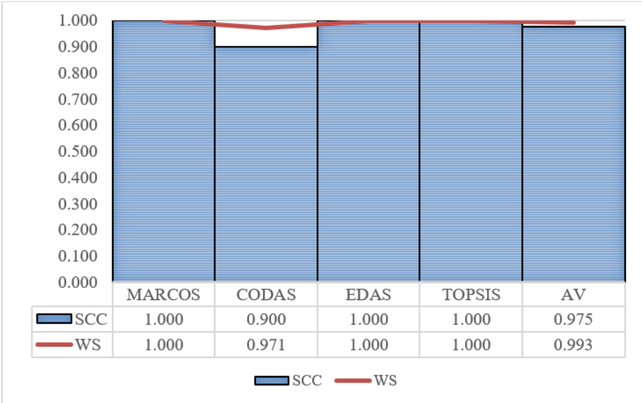

Figure 8. Correlation in comparative analysis

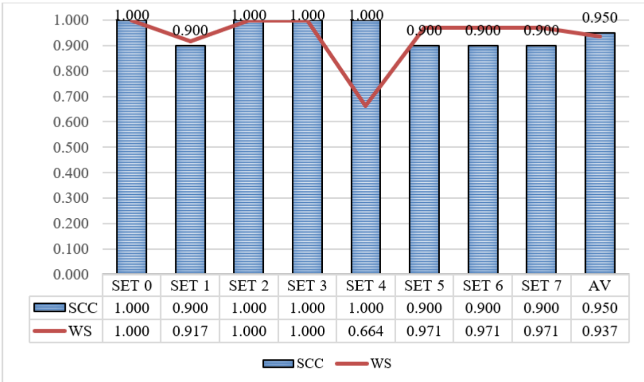

Figure 9. Correlation in sensitivity analysis

The SCC and WS coefficients indicate full correlation in the base case (Set 0) and scenarios Set 2 and Set 3, where both SCC and WS values equal 1.000. In scenarios Set 1, Set 5, Set 6, and Set 7, the SCC values decrease slightly to 0.900, while the WS values remain relatively high at 0.971. A significant deviation occurs in scenario Set 4, where the correlation drops to WS=0.664, likely due to substantial changes in the criteria. Despite this variation, the overall average correlation remains robust, with SCC=0.950 and WS=0.937, indicating that the rankings are stable and consistent across the majority of scenarios.

5 Conclusion

Solid waste management in Libya is still at the rudimentary stage. Although waste collection operations are inefficient, waste accumulates and is disposed of indiscriminately. Wastes, including household, medical, and C&D waste are thrown into landfills. In the years leading up to the 2011 revolution, Libya witnessed the awarding of numerous contracts for construction projects in Libyan cities. The size of these contracts is estimated at more than $150 billion to be implemented over several years, and most of these projects have been suspended as a result of the war. The war has also resulted in severe damage to buildings, especially in the cities where the fighting was concentrated. Previously, demolition and construction waste was disposed of by dumping it in landfills of municipal solid waste, in addition to throwing it randomly, especially on the 1,900 km long beaches. Consequently, local authorities conclude contracts with private companies for the purpose of collecting and transporting debris to the final landfill. Despite the anticipated construction work that will be carried out down the line, policy wordings are failing to keep pace with the uprising environmental and economic problems caused by the massive volumes of demolition quantities and construction products.

The research, on the other hand, outlines the most important criteria that can be used when deciding on the appropriate policy. The FUCOM method has been used for the purpose of determining weights for these criteria. The result has shown that the investment cost criterion is the most important, followed by the social acceptance criterion. The investment cost in such strategic decisions is an important factor, and in relation to the social acceptance criterion, people's acceptance of these sites is usually considered one of the most complex social norms. It also often represents a major challenge for the authorities involved in decision-making on the construction of dumpsites. The importance associated with this criterion can be explained by the influence of community pressure when locking down transshipment sites in many cities due to environmental issues.

There has been an increased awareness of improper waste disposal and its environmental impacts, as well as the possibility of reducing and managing waste; less waste means fewer landfills. Hence, small private companies that collect and export recyclable waste (such as plastic, copper, cardboard, and iron) have been emerging over the last decade. Thus, the existence of such projects plays a crucial role in promoting social stability by creating more employment opportunities and increasing incomes. Therefore, the evaluation of the technologies came in line with this new reality that has begun to take shape, whether in terms of setting a recycling policy as a better alternative or in terms of putting landfills as a last alternative. Even with the change in the weight values of the criteria used, the recycling option has remained the preferred alternative. The implementation of the suggested alternative is still available for additional investigation utilising various techniques for assessing options. Future research could focus on more specific criteria like economic impact, on-site waste management, landfill price, traffic burden, and contractor involvement.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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