Chapter

Perspective Chapter: A Novel Method for Integrated Multicriteria Decision-Making with Uncertainty: A Case Study on Sustainable Agriculture in Colombia

Marc Juanpera, Laia Ferrer-Martí, Marianna Garfí, Bruno Domenech and Rafael Pastor

Abstract

Multicriteria decision-making usually requires a set of experts to evaluate the importance of selected criteria and the adequacy of feasible alternatives according to the criteria. Uncertainty can arise in these evaluations, since experts can be hesitant about their responses due to the difficulty of quantifying human language or lack of required knowledge. The Methodology for Integrated Multicriteria Decision-making with Uncertainty (MIMDU) tackles both factors of uncertainty by using non-predefined fuzzy numbers that are continuously adapted taking into account the level of confidence of the experts' opinions. The methodology also offers useful and complementary information to lead to a robust decision-making. This chapter proposes a novel methodology and provides a sample use case to demonstrate its capability to model uncertainty during decision-making process. In particular, a sensitivity analysis is included, which demonstrates (i) how uncertainty is incorporated into alternatives evaluation, and (ii) that the integrated multicriteria decision-making with uncertainty can be more reliable for decision-makers. The methodology is applied to the robust selection of the most sustainable technology to improve agriculture efficiency in rural areas by means of a case study of a low-cost biogas digester in a small-scale farm in Colombia.

Keywords: multicriteria decision-making, MIMDU methodology, confidence, rural areas development, sustainable agriculture

1. Introduction

Decision-making in industrial and service sectors usually requires selecting one of several feasible alternatives for a specific problem or situation. This selection is not an easy task, since different criteria (e.g., economic, technical, social, environmental, etc.) can be conflicting. Multicriteria decision-making is a suitable approach to handle such problems [1] and usually requires the participation of experts to weigh the criteria and to evaluate the feasible alternatives according to the selected criteria [2]. In particular, for decisions aiming at sustainable development, experts are required to take into account many conflicting criteria with very different nature. These criteria include but not limited to economic (e.g., implementation costs), technical (e.g., systems reliability, ease of maintenance), social (e.g., job creation, degree of acceptance over population), and environmental (e.g., particles emissions, waste generation). Thus, experts are required to evaluate alternatives across all the considered criteria requiring many different expertises. Uncertainties arise due to incomplete knowledge required from experts.

Indeed, experts' opinions are surrounded by two factors of uncertainty: (i) the potential lack of confidence when providing an answer [3], and (ii) the difficulty of quantifying the answer [4]. For example, one expert could hesitate on whether the importance of a criterion should be "high" or "low," and none of those answers has a clear and unequivocal quantification on a numeric scale. Literature has focused until now on the second factor, as proven by the wide use of Fuzzy Linguistic Scales (FLS) in many applications [5, 6]. With FLS, experts are required to choose from different terms (e.g., high or low importance of a criterion), which are quantified through fuzzy numbers (FN) equidistantly disposed along a numerical scale. As an example, **Figure 1** shows numerical scale from 0 to 5. Thus, the same fuzzy number is assigned to two experts considering the importance of a criterion should be, for example, "low," regardless of how confident they are with their answer (e.g., [8]). As it can be seen, such approach does not consider the potential lack of confidence of experts, who can be more informed about some criteria but less about others. Thus, the developed MIMDU presented in this chapter addresses a research gap by considering the lack of confidence in human opinions.

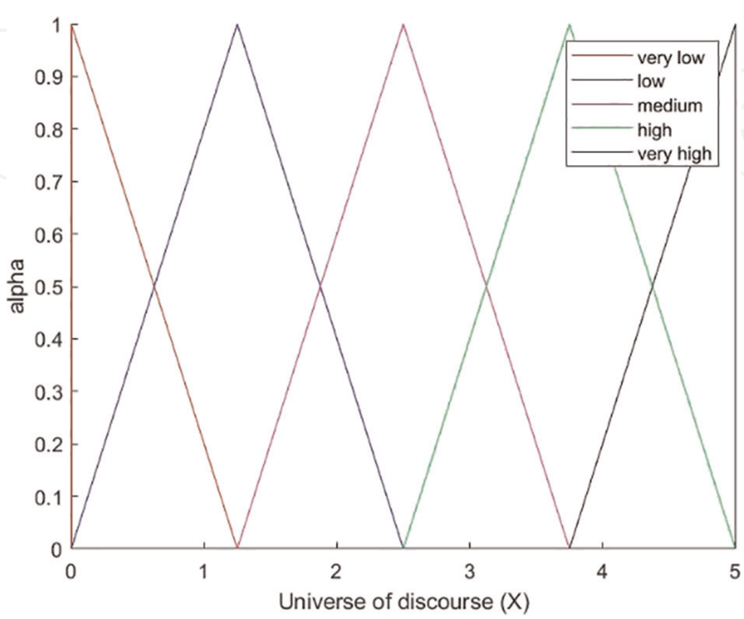

Figure 1.
Usual modeling of FN in literature [7].

The proposed MIMDU methodology can be used to enhance the efficiency of rural agriculture. As an example, the technique is used to increase the quality of a biofertilizer in developing farm areas with biogas digesters. Such biogas digesters degrade cattle manure in anaerobic conditions to produce biogas for cooking or heating and a liquid effluent called digestate [9]. Digestate can be used as a biofertilizer, but it needs to be posttreated for its safe and efficient application to agricultural soil [10].

Different low-tech and low-cost alternatives, coupled with the digesters, can be implemented to posttreat the digestate. In this chapter, the following common posttreatment alternatives are considered to be feasible in a rural context and to allow the stabilization of the organic matter and the reduction of pathogens concentration: (i) a degassing tank, (ii) a sand filter, (iii) a vermifilter, (iv) digestate recirculation in the digester, and (v) a facultative pond. Most of these posttreatment technologies have been studied mainly for the treatment of urban wastewater [11, 12], and only a few studies were carried out with digestates. In this case, a comparative study of alternatives for the posttreatment of digestate from low-tech digesters is missing.

In this context, the aim of this chapter is twofold. First, to demonstrate the novelty of MIMDU to robustly assist multicriteria decision-making considering hesitance in human responses. Second, to apply MIMDU to select the best alternative for digestate posttreatment before its sustainable use in agriculture to enhance crop production. Sesction 2 details the phases of MIMDU, Section 3 provides an example case for illustrative purposes, displays the results of the case study in Colombia, and Section 3 concludes the MIMDU work presented in this chapter.

2. Methodology for integrated multicriteria decision-making with uncertainty (MIMDU)

This section aims to present the process defined by MIMDU, detailing its three phases along with an example case to ease understanding. The three phases include modeling opinions, alternatives ranking, and results interpretation. For comprehension purpose, the example considers a small number of alternatives (e.g., 3) and criteria (e.g., 3), although real case studies can take into account larger numbers of alternatives and criteria, as seen in Section 3. The application of the third phase in the example case is complemented with a sensitivity analysis that aims to show the potential of MIMDU to assist decision-making. Next, the three phases are discussed as follows:

P1. Modeling Opinions: Triangular fuzzy numbers (TFNs) are used in the form of fuzzy rating scales to continuously define the shape of the TFN through intuitive questions gathering the experts' hesitance [13]. Two steps are defined in this phase:

Step 1: The expert must choose a value on a 0–5 scale to rate the importance of a criterion (high value means high importance of the criterion) and to evaluate an alternative according to a criterion (high value means high adequacy of the alternative to the criterion).

Step 2: The expert must express his/her confidence with the reference value expressed in Step 1, from five options presented in **Table 1**. The more confident the expert is, the lower "*support*" (base of the TFN) will have in the answer quantification, and the less vague the quantification will be.

Confidence in the response	Relative support
Completely sure (CS)	0%
Sure (S)	15%
Indecisive (I)	30%
Unsure (U)	45%
Very unsure (VU)	60%

Table 1.
Options to express the level of confidence and quantify the support of the TFN [7].

Criteria	Expert	Importance	Confidence
C1	E1	3	S
	E2	4	I
	E3	1	VU
C2	E1	2	U
	E2	4	S
	E3	4	I
C3	E1	3	S
	E2	3	VU
	E3	5	U

Table 2.
Experts' evaluations of the importance of the criteria [7].

Example case:

This example considers three experts assessing the importance of the three criteria shown in **Table 2**. The adequacy of each alternative according to each criterion is presented in **Table 3**. In both processes, namely rating the importance of the criteria and evaluating the alternatives according to the criteria, each expert first provides a reference value on a 0–5 scale and the associated confidence level, from the options in **Table 1**.

For instance, **Figure 2** illustrates the importance given by the three experts (E1, E2, E3) to C1: E1 is sure on the importance with a score 3 out of 5, E2 is indecisive about it with a score of 4, and E3 rates with a 1 but is very unsure.

This approach establishes a more precise modeling of opinions compared with literature, since TFNs are not defined beforehand. Such flexibility allows to quantify the experts' level of confidence (Step 2) and defines several confidence levels associated with the answers from experts, i.e., concrete or vague answers. The confidence levels have a decisive influence on the ranking of the final alternatives, as shown in Phase 3 (P3) below. Different confidence levels allow the experts to express their potential lack of confidence, which may also reduce the pressure felt by experts when answering, especially in scenarios of limited knowledge or high uncertainty.

P2. Alternatives Ranking: The Compromise Ranking Method (CRM) is used to calculate a final FN for each alternative as an indicator of how good the alternative is compared with the others. For the CRM, this indicator is the distance of each alternative to an ideal solution, which determines the best of all the alternatives across

Criteria	Expert	A1		A2		A3	
		Evaluation (Eval.)	Confidence (Conf.)	Eval.	Conf.	Eval.	Conf.
C1	E1	3	S	2	U	1	U
	E2	3	U	2	VU	3	VU
	E3	4	U	4	CS	5	S
C2	E1	1	VU	1	S	5	U
	E2	2	CS	2	I	4	S
	E3	4	S	2	S	3	S
C3	E1	2	I	1	I	3	CS
	E2	3	VU	2	U	3	S
	E3	5	U	3	S	2	I

Table 3.
Experts' evaluations of the adequacy of alternatives according to criteria [7].

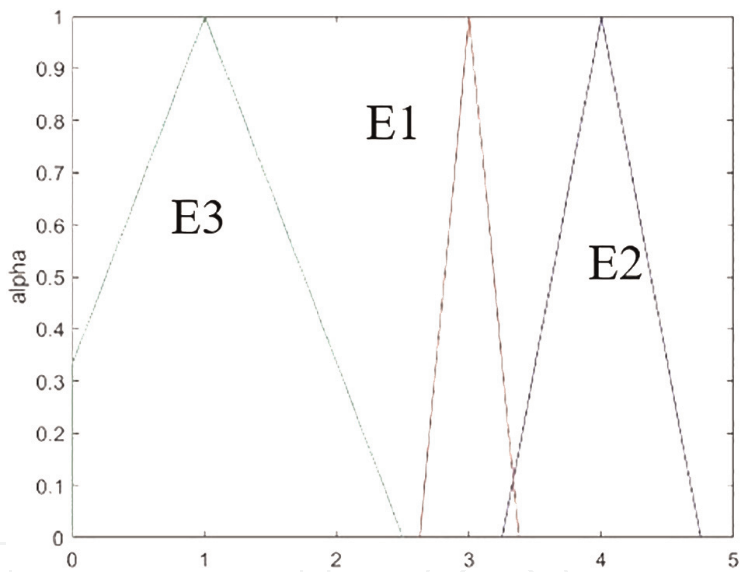

Figure 2.
Modeling of the importance given by the three experts to C1.

selected criteria [14]. The best alternative will be the one with the lower distance to the ideal solution, which is an utopian solution that performs optimally (achieving the best evaluations) for all the criteria considered [7]. In particular, MIMDU includes a fuzzy version of the CRM (F-CRM), represented in Eqs. (1) and (2), using α-cut intervals. Thus, each FN is represented as a sequence of a discrete number of intervals for different cuts (from the bottom α =0, to the top α =1) according to different values of α. The reader is referred to [7] for an exhaustive explanation of the α-cut arithmetic.

$$ {}^{\alpha}L_{i,p} = \left[\sum_{j=1}^{n} \left({}^{\alpha}W_j \right)^p \cdot \left(\frac{ {}^{\alpha}F_j^* - {}^{\alpha}f_{ij} }{ {}^{\alpha}F_j^* - {}^{\alpha}f_j^* } \right)^p \right]^{1/p} \quad (1) $$

$$^{\alpha}L_i = 0.5 \cdot {}^{\alpha}L_{i,1} + 0.5 \cdot {}^{\alpha}L_{i,\infty} \quad (2)$$

Where $^{\alpha}L_{i,p}$ is defined as the standardized distance of each alternative i to the ideal solution for a given metric p, and $^{\alpha}L_i$ is the final distance to the ideal solution and constitutes the final score of the alternative i and allows it to be ranked. In particular, for each value of α, $^{\alpha}W_j$ is the weight of criterion j (an average of opinions on the importance of criterion j by all experts consulted); $^{\alpha}f_{ij}$ is the evaluation of alternative i according to criterion j (also an average of all experts consulted); $^{\alpha}F_j^*$ and $^{\alpha}f_j^*$ are the best and the worst values obtained, respectively, for any alternative on criterion j, and p is a metric used to calculate different distances to the ideal solution (as mentioned above, the one that ideally achieves the best values for all the criteria). An average ($^{\alpha}L_i$) is calculated from the two usual and extreme metrics, p =1, for maximum global utility ($^{\alpha}L_{i,1}$) and p =∞, for the minimum individual regret ($^{\alpha}L_{i,\infty}$) [15].

Example case:

Applying Eqs. (1) and (2) for 11 values of α (from 0 to 1 with a step size of 0.1), the results of the distance to the ideal solution for each alternative ($^{\alpha}L_i$) are shown in **Figure 3**. As it can be seen, all alternatives have distances to the ideal solution above 0. Intuitively, it seems that A1 and A3 achieve lower distances than A2, so the latter could be discarded. However, the "Results Interpretation" phase is useful to discuss which one is the best (minor distance), since fuzzy numbers are clearly overlap in this example.

P3. Results Interpretation: As mentioned in P2, ranking alternatives from their fuzzy values might be misleading (e.g., in the above example, it is not clear if A1 or A3 achieve a lower fuzzy distance to the ideal solution). Thus, a comparison of a crisp ranking and a fuzzy-based ranking is proposed:

Crisp ranking: it is determined by the results of $^{1}L_i$, which does not consider the experts' level of confidence, but only the numerical values responded by the experts in Step 1. This deterministic ranking is intrinsically significant and meant the only decision-aid source in relevant studies of the literature [2, 16].

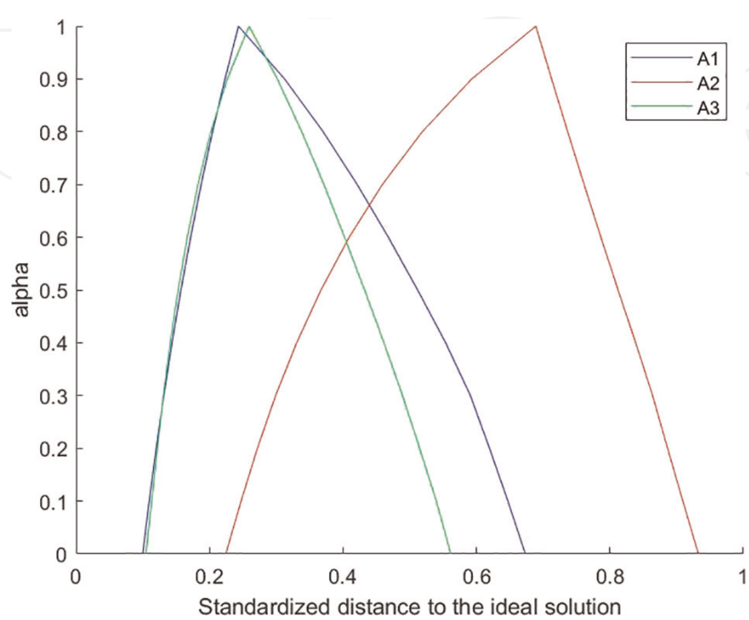

Figure 3.
FN for the distance of A1–A3 to the ideal solution [7].

Fuzzy-based: The Middle Point of the Mean Interval (MPMI) described in Eq. (3) is used to calculate the best non-fuzzy performance value of each final FN ($^{\alpha}L_i$) [17]. This method integrates, for each alternative, the average of the lowest and highest value for each α-cut interval of the distance of the alternative to the ideal solution:

$$\mathrm{MPMI_i} = \int_0^1 \frac{\min\ ^{\alpha}\mathrm{L_i} + \max\ ^{\alpha}\mathrm{L_i}}{2} \mathrm{d}\alpha \qquad (3)$$

Example case:

Table 4 shows both the crisp ranking and the fuzzy-based values that can be used to rank the alternatives. As shown in **Table 4**, the two rankings diverge. According to the crisp ranking, the best alternative would be A1 (lower distance to the ideal solution), followed by A3 and A2, i.e., A1-A3-A2. These results can be observed at the top of **Figure 3** (only values for α =1). However, for the fuzzy-based ranking, which considers the level of confidence of the experts, the ranking of the alternatives would be A3-A1-A2. The difference occurs because A1 has been better evaluated than A3 by the experts when expressing numerical values for their adequacy to each criterion (Step 1), but at the same time, they expressed a lower level of confidence (Step 2). Oppositely, A3 has been evaluated slightly worse, but more confidently, which eventually can make A3 a more reliable choice when assessing the whole experts' opinions.

In line with this discussion, and in order to fully show the potential of MIMDU to assist decision-making, a sensitivity analysis was carried out by modifying the evaluations of A3 according to C3 performed by expert E3. In particular, it is considered that this expert evaluates A3 according to C3 with the same reference value of 2 as shown in the last row of **Table 3**. But for this case, it evaluates A3 with the five options of confidence levels: CS, S, I, U, VU (i.e., five scenarios), instead of only the original I. **Table 5** shows the non-fussy performance value of the distance of alternative A3 to the ideal solution ($MPMI_{A3}$) for all confidence scenarios. It can be seen that the lowest distance, and thus the best ranking-value of alternative A3, is obtained when E3 is completely sure (CS) of their evaluation of A3. Meanwhile, the worst ranking-value of A3 is achieved when he/she is very unsure (VU) of the evaluation. This result is consistent with the process detailed and is understandable, since more confidently evaluated alternatives are achieving better ranking results.

Those two extreme values ($MPMI_{A3}$ when the expert is CS and when he/she is VU) can be compared with $MPMI_{A1}$, which remains unchanged, i.e., when $MPMI_{A3}$ in the VU confidence case is 9.42% lower than the one for A1 (0.298 against 0.329;

	A1	A2	A3
Crisp: $^{1}L_i$	**0.243**	0.689	0.259
Fuzzy-based: $MPMI_i$	0.329	0.603	**0.294**

Table 4.
Crisp and fuzzy rankings of the alternatives in the example case [7].

E3	CS	S	I (original)	U	VU
$MPMI_{A3}$	0.290	0.292	0.294	0.296	0.298

Table 5.
Sensitivity analysis on the hesitance on the evaluation of A3 for E3.

Tables 4 and **5**, respectively); it increases up to 11.85% lower for the CS case (0.290 against 0.329; **Tables 4** and **5**, respectively). This means there is a difference of 25.80% (11.85 vs. 9.42%) between the distances of A1 and A3 with only one expert changing the level of confidence of the evaluation. It seems then that the level of confidence plays an important role in the final ranking of the alternatives, in which alternatives evaluated more confidently, such as A3 stands out.

3. Application: selection of the best alternative for digestate posttreatment for low-cost digesters in small-scale farms

This section describes the application of MIMDU to select the best alternative to posttreat the digestate before its sustainable use as a biofertilizer in agriculture.

3.1 Alternatives presentation and criteria definition

Five low-tech alternatives are considered to treat the digestate obtained in a low-cost biogas digester implemented in a small farm in Colombia. As shown in **Figure 4**, all alternatives are implemented just after the biogas digester to posttreat the digestate. The five alternatives are given below:

- A1. Degassing tank alternative: It allows the recovery of the remaining diluted methane and stabilizes the organic matter producing more biogas.

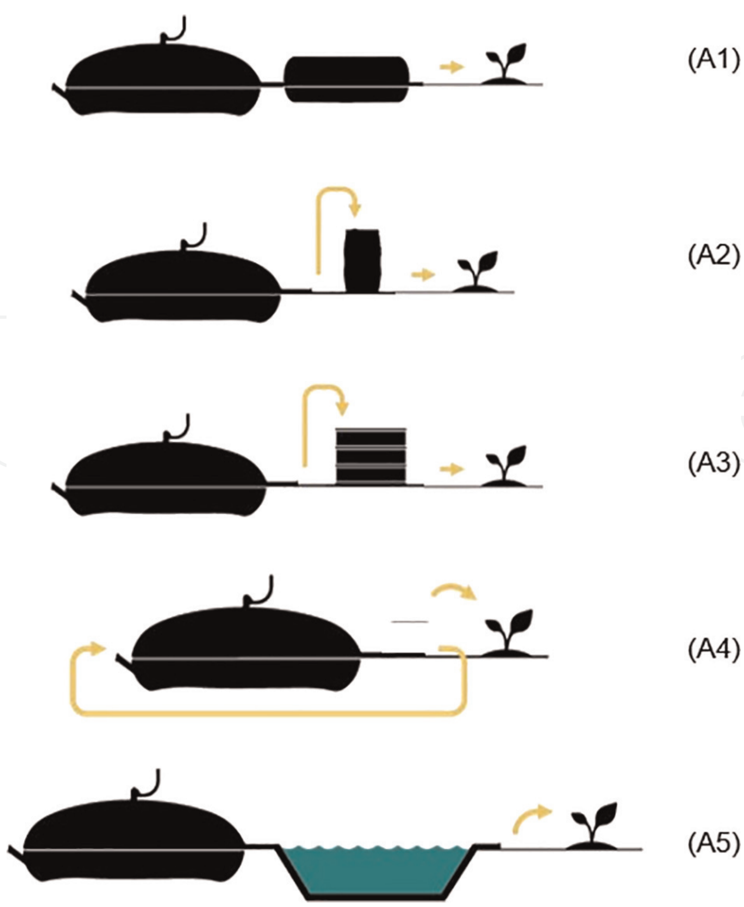

Figure 4.
Five alternatives for digestate posttreatment, Adapted from [18].

- A2. Sand filter alternative: It employs both physical and biological processes, without energy outputs, to reduce the digestate turbidity and remove suspended solids and pathogens.

- A3. Vermifilter alternative: It consists of a biofilter with earthworms that helps to accelerate the decomposition of organic matter. The earthworms' activity increases the porosity of the fertilizer obtained from the organic matter, called vermicompost, creating aerobic conditions that avoid the emission of unpleasant odors.

- A4. Digestate alternative: Recirculation into the digester. This is a simple solution that allows recovering the diluted methane and stabilizes the organic matter while saving water.

- A5. Facultative pond alternative: It can be a shallow basin that aims to remove pathogens and ammonia nitrogen, as well as treating the effluent. Facultative ponds benefit from high solar radiation, which enhances bacterial activity.

Also, combining alternatives in series (e.g., A1 + A2, A1 + A3, and A1 + A5) has been also considered for their complementary nature. Other combinations were not realistic in practice for small farms in rural areas.

These five alternatives are evaluated according to 10 criteria and 22 (sub)criteria (**Table 6**), selected after discussion with experts in the field and divided into three categories, namely technical, environmental, and socioeconomic [19]. The categories are defined as follows:

- Technical criteria (T) aim to assess the suitability of the posttreated digestate for agriculture, which demands a reduced amount of heavy metals and pathogens and a high content of dry matter, organic matter, and nutrients. They also take into account the adaptability of the alternative to the context of small-scale farms in countries with low income, stating how easy to manage they are, the area they require, and their expected lifetime.

- Environmental (E) criteria focus on evaluating the impact of the alternatives for digestate posttreatment. The criteria include air pollution (emission of particles, greenhouse gases, and odors) and the resources they consume (whether they use sustainable and local materials, and the amount of water and energy demanded).

- Socioeconomic (S) criteria study the possible harmful and benefitting consequences of the alternatives in the everyday life of the population. It considers aspects such as the cost of implementation and maintenance, the potential income generation and savings it can provide for the families (for example, due to improved agriculture production), and the social acceptance of the population, which can be based on positive or negative past experiences.

3.2 Modeling uncertainty

A total of 16 experts from the network for Biodigesters in Latin America and the Caribbean (RedBioLAC, 2020 edition) participated in a survey to define the importance of each criterion using the MIMDU procedure. As an example, the assessments

Aspects	Criteria		Sub-criteria		E1		E2		...	E16	
					Eval.	Conf.	Eval.	Conf.		Eval.	Conf.
Technical	T1	Digestate characteristics	T1.1	Heavy metals content	3	U	2	I	...	5	U
			T1.2	Pathogens content	3	I	3	I		5	U
			T1.3	Dry matter content	2	I	3	VU		2	I
			T1.4	Organic matter content	2	I	3	VU		2	I
			T1.5	Nutrients content	4	S	4	I		4	I
			T1.6	Diluted biomethane	4	VS	4	VS		4	I
	T2	Management	T2.1	Skilled labor	4	S	5	VS		3	S
			T2.2	Ease of construction and maintenance	3	S	3	S		5	I
			T2.3	Ease of maintenance	4	S	3	VS		5	I
	T3	Surface area requirement	—	Surface area requirement	3	S	2	U		5	U
	T4	Lifespan	—	Lifespan	4	S	4	VU		5	U
Environmental	E1	Air pollution	E1.1	Emission of particulate matter, greenhouse gases and sulfur oxides	3	I	4	VS		4	I
			E1.2	Emission of odors	3	I	5	VS		4	S
	E2	Resources consumption	E2.1	Sustainability of materials	4	S	3	U		5	S
			E2.2	Water consumption	4	S	3	I		5	S
			E2.3	Energy consumption	4	S	2	VU		3	I
Socio-economic	S1	Costs	S1.1	Initial investment	4	S	5	S		5	VS
			S1.2	Maintenance costs	4	S	3	VS		5	S
	S2	Benefits	S2.1	Income generation	4	S	2	I		5	S
			S2.2	Savings	3	I	1	VU		5	VS
	S3	Standard of living	S3	Equity and standard of living	4	I	3	VU		5	VS
	S4	Social acceptance	S4	Social acceptance	4	S	5	VS		5	VS

Table 6.
Criteria and subcriteria defined and evaluation of their importance.

of three experts are shown in **Table 6**, reflecting their differences according to the technical or academic background of each expert (E1 and E2 have industry technical background and E16 has academic training). When looking at the socioeconomic criteria, it is observed that experts E1 and E2 evaluated their importance with less confidence level than E16, who is either sure or very sure (S and VS) of their high importance. Oppositely, E16 has different opinions on the importance of the technical criteria (for example, he/she assigns a 5 to the digestate content of heavy metals and pathogens, and a 2 to the dry, organic matter and nutrients contents), but is in all cases indecisive (I) and unsure (U) about the evaluations. Hence, the use of MIMDU allows to capture that uncertainty and modeling the responses consequently.

Regarding the evaluations of the alternatives, the uncertainty modeling is tackled differently according to the quantitative and qualitative nature of each (sub)criterion, and they are given below.

Quantitative (sub)criteria are T1, T3, T4, E2.2, E2.3, and S1. For these (sub) criteria, a reference value of the evaluations is obtained with real data collected in situ. Such real data embraced parameters of the construction and operation of the full-scale digesters in Colombia (e.g., biogas production and quality characteristics of the digestate, including heavy metals, pathogens, organic matter, nutrients, etc.). On the other hand, the impact of the alternatives on those digestate parameters, such as reduction rates for the metal or pathogens content, and increase rates for the dry, organic matter and nutrients, are taken from the literature [11, 20, 21]. The alternatives are also sized (determining the surface and volume required to process the digestate coming from the biogas digester, and the materials needed) to obtain an initially estimated of the initial investment and maintenance cost from the amount of materials needed in each alternative. Finally, to define a TFN, a 10% deviation from the reference value is considered to account for uncertainty on the inherent data obtained. This 10% was agreed among the experts involved in the decision-making as an appropriate estimation of the deviation of measures of biogas digester's and digestate's parameters. The specific detail of the evaluation of the alternatives according to the quantitative (sub)criteria for the specific case study can be found in [19].

Qualitative (sub)criteria are T2, E1, E2.1, S2, S3, and S4. For these (sub)criteria, a similar procedure explained in Section 2 is used to evaluate the alternatives. An assessment of 0–5 is assigned to each pair alternative-criterion according to how much the alternative fulfills the criterion, and a ± 1 deviation is considered to account for the potential uncertainty in the human judgment due to hesitance. Similarly, specific details of the evaluation of the alternatives according to the qualitative (sub)criteria can be found in [19].

3.3 Alternatives ranking and discussion

From the experts' opinions on the criteria weights and the evaluations of the alternatives, the F-CRM is applied using Eqs. (1) and (2), and the corresponding MPMI is calculated for each alternative. **Table 7** shows the results of the crisp and the fuzzy-based ranking of all the alternatives considered for digestate post-treatment in small-scale farms located in rural. The vermifilter (A3) appears to be the best posttreatment alternative for both rankings, followed by recirculation (A4) and sand filtration (A2) alternatives. The similarity between the crisp and fuzzy rankings confirms the robustness of the results, since it means that the uncertainty included in both weights and evaluations does not modify the result achieved due to the crisp opinions

	A1	A2	A3	A4	A5	A1 + A2	A1 + A3	A1 + A5
${}^{1}L_i$	0.348	0.309	**0.186**	0.272	0.406	0.414	0.331	0.486
Crisp ranking	5	3	**1**	2	6	7	4	8
$MPMI_i$	0.358	0.293	**0.213**	0.288	0.394	0.391	0.329	0.450
Fuzzy-based ranking	5	3	**1**	2	7	6	4	8

Table 7.
Crisp and fuzzy rankings of the alternatives for digestate post-treatment [19].

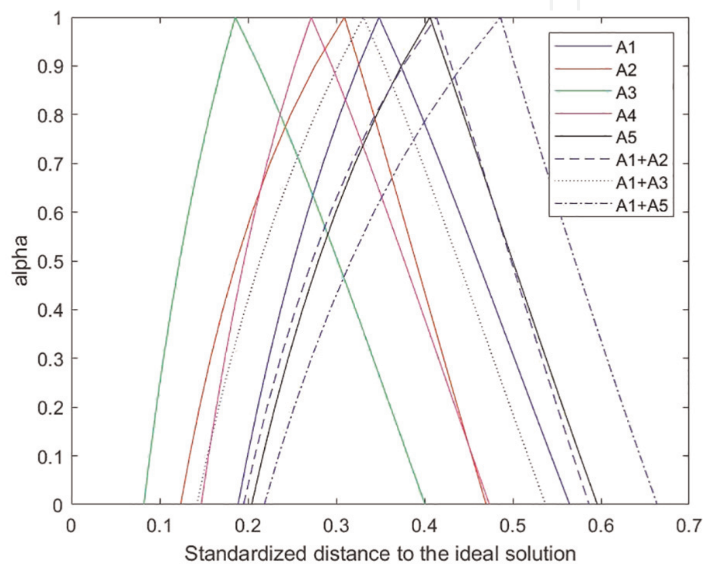

Figure 5.
FN for the distance of A1 – A1 + A5 to the ideal solution [19].

of experts. **Figure 5** offers a representation of the FN and is in accordance with the conclusions provided. The results show that the distance of A3 to the ideal solution is clearly lower than the others alternatives, i.e., the corresponding FN is placed more to the left. These results should ease and increase the confidence of decision-makers.

The overall predominance of the vermifilter alternative (A3) relies on its capacity of generating a final product (vermicompost), which is easier to implement, manage, and transport, and at the same time, it is a high-quality biofertilizer that can increase the agriculture production and has itself market potential for being sold [22]. In consequence, it accounts for the best evaluation in some of the environmental and socioeconomic criteria, such as the sustainability of materials needed for its implementation (basically wood, E2.1) and its capacity of generating income for the beneficiary population (S2.1). Alternatively, coupling a degassing tank and a vermifilter in series (i.e., combined A1 and A3, a.k.a. A1 + A3) enhances even more the quality of the digestate, since diluted methane is highly recovered (T1.6), but represents significantly greater economic investments for implementation and day-to-day operation.

Other well-ranked alternatives are recirculating the digestate alternative (A4) and implementing a sand filter alternative (A2). A4 is very easy to implement, does not require skilled labor (T2.1, T2.2) nor surface area (T3), and reduces the amount of water that feeds the digester (E2.2). Meanwhile, A2 drastically reduces the heavy metals content (T1.1) and has a long life span (T4).

4. Conclusions

MIMDU is a novel Methodology for Integrated Multicriteria Decision-Making with Uncertainty that focuses on integrating the experts' level of confidence into their responses. The method is divided into three phases, namely modeling opinions (P1), ranking alternatives (P2), and interpreting the results (P3). Compared with other multicriteria methods available in the literature (such as VIKOR and TOPSIS [1]), MIMDU offers two key features, including (1) generate better estimation of the opinions collected from experts incorporating their various levels of confidence through predefined TFN, and (2) provide complimentary information for a robust decision-making, including a crisp ranking without uncertainty consideration and a fuzzy-based ranking incorporated uncertainty considerations. These MIMDU's features enable a robust decision-making process.

To ease comprehension, MIMDU was demonstrated for a generic example case with reduced size. An example using three criteria and three alternatives was provided. Results obtained from this example showed that the proposed MIMDU procedure helps decision-makers to choose the most reliable alternative, as significant differences in the ranking "without" and "with uncertainty" can be quantified and compared. Specifically, for the example use case, the crisp ranking showed that alternative A1 is 6.58% better than alternative A3; but when the level of confidence is considered, A3 turns out to be 10.64% better; and hence A3 is selected as the best alternative as compared with A1 and A2. Also, the effect of lower or higher confidence in the response is tackled within a sensitivity analysis. Results show that increasing the confidence when evaluating an alternative can significantly improve its performance in the final ranking.

Finally, the proposed MIMDU was demonstrated for digestate posttreatment in small-scale farms with low-cost biodigesters. Both the crisp and fuzzy-based ranking results pointed out that the vermifilter alternative is the best option, followed by recirculating the digestate and the sand filter alternatives. In particular, the vermifilter is confirmed as an environmental-friendly technology that is allowed to create a high-quality product (vermicompost) to increase agricultural productivity and also generate incomes to the families due to sales. The consideration of uncertainty in both the experts' opinions and the alternatives evaluation demonstrated that MIMDU is a robust decision-making method for agriculture applications. The proposed MIMDU procedure described in this chapter can be extended to other applications.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Marc Juanpera[1]*, Laia Ferrer-Martí[2], Marianna Garfí[3], Bruno Domenech[1] and Rafael Pastor[1]

1 Department of Management, Universitat Politècnica de Catalunya—BarcelonaTECH, Spain

2 Department of Mechanical Engineering, Universitat Politècnica de Catalunya—BarcelonaTECH, Spain

3 Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya—BarcelonaTECH, Spain

*Address all correspondence to: marc.juanpera@upc.edu

References

[1] Opricovic S, Tzeng G. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research. 2004;**156**:445-455. DOI: 10.1016/S0377-2217(03)00020-1

[2] Domenech B, Ferrer-Martí L, Pastor R. Hierarchical Methodology to Optimize the Design of Stand-Alone Electrification Systems for Rural Communities considering Technical and Social Criteria. Renewable and Sustainable Energy Reviews. 2015;**51**: 182-196. DOI: 10.1016/j.rser.2015.06.017

[3] Chen S-M, Hong J-A. Multicriteria linguistic decision making based on hesitant fuzzy linguistic term sets and the aggregation of fuzzy sets. Information Sciences. 2014;**286**:63-74. DOI: 10.1016/j.ins.2014.06.020

[4] Zadeh LA. The concept of a linguistic variable and its application to approximate reasoning - I. Information Sciences. 1975;**8**:199-249. DOI: 10.1016/ 0020-0255(75)90036-5

[5] Abdel-Baset M, Chang V, Gamal A, Smarandache F. An Integrated Neutrosophic ANP and VIKOR Method for Achieving Sustainable Supplier Selection: A Case Study in importing Field. Computers in Industry. 2019;**106**: 94-11. DOI: 10.1016/j.compind.2018. 12.017

[6] Rostamzadeh R, Govindan K, Esmaeili A, Sabaghi M. Application of fuzzy VIKOR for evaluation of green supply chain management practices. Renewable and Sustainable Energy Reviews. 2015;**51**:182-196. DOI: 10.1016/ j.ecolind.2014.09.045

[7] Juanpera M, Domenech B, Ferrer-Martí L, García-Villoria A, Pastor R. Methodology for Integrated Multicriteria Decision-Making with Uncertainty: Extending the Compromise Ranking Method for Uncertain Evaluation of Alternatives. Fuzzy Sets and Systems. 2022;**2022**(434):135-158. DOI: 10.1016/ j.fss.2021.08.008

[8] Shojaie AA, Babaie S, Sayah E, Mohammaditabar D. Analysis and Prioritization of Green Health Suppliers Using Fuzzy ELECTRE Method with a Case Study. Global Journal of Flexible Systems Management. 2018;**19**:39-52. DOI: 10.1007/s40171-017-0168-2

[9] Ferrer I, Garfí M, Uggetti E, Ferrer L, Calderon A, Velo E. Biogas production in low-cost household digesters at the Peruvian Andes. Biomass and Bioenergy. 2011;**35**(5):1668-1674. DOI: 10.1016/ j.biombioe.2010.12.036

[10] Garfi M, Martí-Herrero J, Garwood A, Ferrer I. Household anaerobic digesters for biogas production in Latin America: A review. Renewable and Sustainable Energy Reviews. 2016;**60**:599-614. DOI: 10.1016/j.rser.2016.01.071

[11] Patil PM, Husain M. Enhancing Efficiency of Anaerobic Digestion by Sand Filtration of Effluent. American Journal of Environmental Engineering. 2019;**9**(1):12-15. DOI: 0.5923/j.ajee.2019 0901.03

[12] Krishnasamy K, Nair J, Hughes RJ. Vermifiltration systems for liquid waste management: A review. International Journal of Environment and Waste Management. 2013;**12**:4. DOI: 10.1504/ ijewm.2013.056908

[13] Lubiano MA, Rosa de Sáa S, Montenegro M, Sinova B, Gil MA.

Descriptive Analysis of Responses to Items in Questionnaires. Why not Using a Fuzzy Rating Scale? Information Sciences. 2016;**360**:131-148. DOI: 10.1016/j.ins.2016.04.029

[14] Zeleny M. Compromise programming. Multiple criteria decision making. Columbia: University of South Carolina Press; 1973. pp. 263-301

[15] Yücenur GN, Demirel NÇ. Group decision making process for insurance company selection problem with extended VIKOR method under fuzzy environment. Expert Systems with Applications. 2012;**39**:3702-3707. DOI: 10.1016/j.eswa.2011.09.065

[16] Ferrer-Martí L, Ferrer I, Sánchez E, Garfí M. A multi-criteria decision support tool for the assessment of household biogas digester programmes in rural areas. A case study in Peru. Renewable and Sustainable Energy Reviews. 2018;**95**:74-83. DOI: 10.1016/j.rser.2018.06.064

[17] Dubois D. Possibility Theory and Statistical Reasoning. Computational Statistics and Data Analysis. 2006;**51**: 47-69. DOI: 10.1016/j.csda.2006.04.015

[18] Monteagudo S. Desarrollo de un análisis multicriterio para la selección de alternativas sostenibles para el postratamiento del efluente de biodigestores de bajo coste [thesis]. Barcelona, Spain: Universitat Politècnica de Catalunya; 2020

[19] Juanpera M, Ferrer-Martí L, Diez-Montero R, Ferrer I, Castro L, Escalante H, et al. A robust multicriteria analysis for the post-treatment of digestate from low-tech digesters. Boosting the circular bioeconomy of small-scale farms in Colombia. Renewable and Sustainable Energy Reviews. 2022;**166**:112638

[20] Mara D. Domestic Wasterwater Treatment in Developing Countries. Earthscan; 2003. p. 311. ISBN: 1-84407-019-0. Available at: https://www.pseau.org/outils/ouvrages/earthscan_ltd_domestic_wastewater_treatment_in_developing_countries_2003.pdf

[21] Garg P, Gupta A, Satya S. Vermicomposting of different types of waste using Eisenia foetida: A comparative study. Bioresource Technology. 2006;**97**:391-395. DOI: 10.1016/j.biortech.2005.03.009

[22] Kannadasan N, Balasubramanian B, Palanisamy T, Shanmugam S, Pushparaj K, Al-Dhabi NA, et al. Sustainable biotreatment of textile dye effluent water by using earthworms through vermifiltration. Journal of King Saud University – Science. 2021;**33**: 101615. DOI: 10.1016/j.jksus.2021.101615