Methodology for Integrated Multicriteria Decision-Making with Uncertainty (MIMDU) for Robust Analysis. Case Study about Agricultural Efficiency in Colombia

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Abstract. Selecting the best among different alternatives may require asking for experts' opinions to weight key criteria and assess the alternatives. Their opinions can be: 1) hesitant, and 2) difficult to quantify on a numerical scale. The Methodology for Integrated Multicriteria Decision-making with Uncertainty (MIMDU) allows performing robust multicriteria analysis considering both factors of uncertainty. Fuzzy rating scales are integrated into the Compromise Ranking Method to finally rank alternatives based on a comparison of a crisp ranking (without uncertainty) and a fuzzy-based ranking (with uncertainty). The soundness of MIMDU is shown with an example case which highlights its capacity of precisely modelling uncertain opinions and assist decision-making. Finally, MIMDU is used to select the most sustainable technology to improve agriculture efficiency in rural underprivileged areas by means of a real small-scale farm in Colombia.

Keywords: Multicriteria decision-making, MIMDU, confidence, uncertainty rural areas development, agricultural efficiency.

1 Introduction

The management of industrial and service sectors requires making decisions, which usually involve selecting one of several feasible alternatives. This selection is not an easy task, since different criteria (e.g. economic, technical, social, environmental) can be conflicting. Multicriteria decision-making is a suitable approach to handle such problems, and usually requires the participation of experts to weight the criteria and assess feasible alternatives [1, p.188].

Experts' opinions are surrounded by uncertainty due to two factors: the potential lack of confidence when providing an answer (for example, if the importance of a criterion should be high or low) and the difficulty of quantifying the answer. Literature has until now focused on the second factor, as proven by the wide use of Fuzzy Linguistic Scales (FLS) in industrial applications and for sustainable development [2, p.97]. 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 distributed along a numerical scale. However, 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 Methodology for Multicriteria Decision-Making with Uncertainty (MIMDU) addresses a research gap by considering the lack of confidence in human opinions.

For decisions aiming at sustainable development, experts are required to take into account at the same time economic criteria (e.g. implementation costs), technical (e.g. systems reliability, ease of maintenance), social (e.g. job creation, degree of acceptance over population), or environmental (e.g., particles emissions, waste generation). Thus, it often occurs that the limited expertise of an expert does not reach all the considered criteria, and hesitance can more easily arise. In this work, we enhance the efficiency of low-cost biogas digesters, which have been implemented in Colombia. Such digesters degrade cattle manure in anaerobic conditions to produce biogas, for cooking or heating, and a liquid effluent called digestate. Digestate can be used as a biofertilizer, but it needs to be post-treated for its safe and efficient application to agricultural soil.

In this context, the aim of this study is to present the developed MIMDU to robustly assist multicriteria decision-making and apply it for the first time to select the best alternative for digestate post-treatment before its efficient use in agriculture. The rest of the study details the phases of MIMDU (section 2), displays the results of the case study in Colombia (section 3) and concludes the work (section 4).

2 MIMDU. Process and Potential

MIMDU is composed of three phases (P1-P3):

P1. Modelling Opinions: Triangular FN are used in the form of fuzzy rating scales [3, p.133] to model uncertain opinions. Two steps are defined:

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) 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 above reference value, from five options (Table 1). The less confident is the expert, the higher support (base of the FN) will have the answer quantification: e.g. Fig. 1 shows example answers of three experts (E1-E3) for the importance of a criterion: E1 is *sure* the importance is 3 out of 5, E2 is *indecisive* about it being 4 and the E3 rates it with a 1 but is *very unsure*.

Table 1. Options to express the level of confidence and quantify the support of the FN

Confidence in the response	Relative support
Completely sure	0%
Sure	15%
Indecisive	30%
Unsure	45%
Very unsure	60%

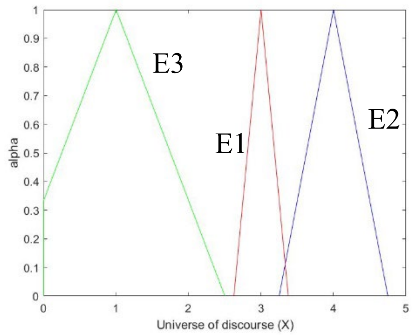

Fig. 1. Example of answers for three different experts (Source: [4, p.147])

This approach establishes a more precise modelling of opinions compared to literature, since FN are not defined beforehand, and may reduce the pressure felt by experts when answering, as they express their lack of confidence.

P2. Alternatives Ranking: The Compromise Ranking Method (CRM) is used, which aims to calculate the distance of each alternative to an ideal solution which is the best of all the alternatives for all the criteria. In particular, a fuzzy version F-CRM is defined (1) and (2) using α-cut intervals. The reader is referred to [4, p.139] for an exhaustive explanation of α-cut arithmetic.

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

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

where $^{\alpha}W_j$ is the weight of criteria j, $^{\alpha}f_{ij}$ is the evaluation of alternative i according to criterion j, $^{\alpha}F_j^*$ and $^{\alpha}f_j^*$ are the best and worst value obtained for any alternative on criterion j, and p allows to calculate different distances to the ideal solution. 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 ($^{\alpha}L_{i,\infty}$).

Applying (1) and (2) for 11 values of α (from 0 to 1, time-step: 0.1) in a case with

3 alternatives (A1-A3) [4, p. 146], the results of the distance to the ideal solution for each alternative (${}^{\alpha}L_i$) are shown in Fig. 2. As it can be seen, all alternatives have distances to the ideal solution above 0. Also, a Results Interpretation phase is useful to highlight which one is the best (minor distance), since fuzzy numbers clearly overlap.

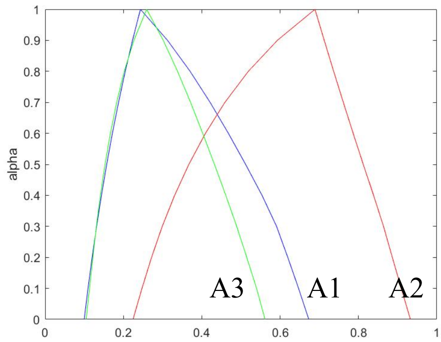

Fig. 2. FN for the distance of A1-A3 to the ideal solution (Source: [4, p.150])

P3. Results Interpretation: Ranking alternatives from their fuzzy values might be misleading (e.g. it is not clear if A1 or A3 achieves lower fuzzy distance to the ideal solution). Thus, a comparison of a crisp and a fuzzy-based analysis is proposed:

- Crisp: the results of ${}^{1}L_i$, which does not consider the experts' confidence. This result meant the only decision-aid source in some studies [1, p.191].
- Fuzzy-based: The Middle Point of the Mean Interval [5, p.63] is used to calculate a best non-fuzzy performance value (3):

$$MPMI(\tilde{A}) = \int_0^1 \frac{min\ {}^{\alpha}A + max\ {}^{\alpha}A}{2} d\alpha \qquad (3)$$

Table 2 shows that the two rankings diverge and, taking into account the uncertainty introduced by experts' lack of confidence, the preferable alternative should be A3.

Table 2. Crisp and fuzzy rankings of the alternatives in the example case

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

3 Application: Selection of the Best Alternative for Digestate Post-treatment for Low-Cost Digesters in Small-Scale Farms

Five alternatives are considered to treat the digestate obtained in a low-cost biogas digester in a small farm in Colombia:

- A1. Degassing tank. to recover the remaining diluted methane.
- A2. Sand filter, to reduce the digestate turbidity and remove suspended solids and pathogens
- A3. Vermifilter: to accelerate the decomposition of organic matter with a biofilter composed of earthworms.
- A4. Recirculating the digestate once again into the digester to recover the remaining methane and stabilizing the organic matter.
- A5. Facultative pond, shallow basins to remove pathogens, remove ammonia nitrogen and clarify the effluent.

Also, combined alternatives are considered: A1+A2, A1+A3 and A1+A5.

After designing the alternatives from input data of the digestate characteristics obtained in-situ, they have been evaluated according to several criteria, which included: metals and pathogens removal, ease of maintenance, investment and operation cost, sustainability of materials and degree of acceptance by population.

Table 3 shows the results of the crisp and the fuzzy-based ranking, which allow to robustly conclude that the best alternative is the Vermifilter (A3), which produces a high-quality fertilizer with sustainable materials.

Table 3. Crisp and fuzzy rankings of the alternatives for digestate post-treatment

	A1	A2	**A3**	A4	A5	A1+A2	A1+A3	A1+A5
Crisp	0.348	0.309	**0.186**	0.272	0.406	0.414	0.331	0.486
Fuzzy-based	0.358	0.293	**0.213**	0.288	0.394	0.391	0.329	0.450

4 Conclusions

MIMDU presents two major contributions: 1) a better estimation of hesitant opinions due to the flexibility when defining the FN; and 2) complimentary information for a robust decision-making, highlighting the effect of uncertainty in the ranking results. It has been applied to robustly select the Vermifilter as the best digestate post-treatment technique for small-scale farms with low-cost biodigesters.

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References

1. 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. Ren. Sus. Energy Rev. 51, 182–196 (2015)
2. 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 Importin Field. Comp. in Indus. 106, 94–11 (2019)
3. Lubiano, M.A., Rosa de Sáa, S., Montenegro, M., Sinova, B., Gil, M.A.: Descriptive Analysis of Responses to Items in Questionnaires. Why not Using a Fuzzy Rating Scale? Inform. Sci. 360, 131–148 (2016)
4. 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 Sys. 434, 135-158 (2022)
5. Dubois, D. Possibility Theory and Statistical Reasoning. Comp. Stat. Data Analysis. 51, 47-69 (2006)