Evaluation of Sustainability for Turkey's Cities with Hesitant Fuzzy Linguistic MCDM Methods

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***Abstract**. In the globalizing world, regions and cities are competing, not states. In these conditions, it is crucial for the sustainability of cities to evaluate their current situation in economic, social, and environmental dimensions, to determine their development strategies, and to keep up with this change in a planned way. The concept of sustainable development, which provides economic, social, and environmentally balanced development, appears at this point. In this context, the evaluation of the sustainability for Turkey's cities is considered as a Multi-Criteria Decision Making (MCDM) problem. The heterogeneous structure of the sustainability evaluation includes a number of contradicting factors. It is difficult to choose and rank alternatives when information is uncertain. The hesitant fuzzy linguistic term set approach addresses the problem's uncertainty-related difficulties. The study aims to present an integrated hesitant fuzzy linguistic (HFL) MDCM approach to assess sustainability for Turkey's cities. The factors are weighted with HFL Simple Additive Weighting (SAW). Then, cities are evaluated with the HFL Multi-Attributive Border Approximation Area Comparison (MABAC) method. Finally, a case study illustrates the possibilities of this method.*

Keywords. Hesitant fuzzy linguistic term set, MABAC, multi-criteria decision making, SAW, sustainability, sustainability evaluation

1 Introduction

Turkey is in the process of rapid change together with the entire world. In the globalizing world, regions and cities are competing, not states. In these conditions, it is crucial for the sustainability of cities to evaluate their current situation in economic, social, and environmental dimensions, to determine their development strategies and keep up with this change in a planned way (Zhou et al., 2019).

A sustainable city is defined as a city that maximizes economic and social benefit while ensuring socio-economic equality in the future distribution of opportunities suitable for the restrictive conditions of the environment. Sustainability requires putting together values such as nature protection, social equality, meeting basic human needs, as well as economic and political issues such as physical infrastructure, economic vitality, and the labor market (Tanguay et al., 2010).

Sustainable cities aim to reduce their ecological footprint as much as possible by turning to renewable energy sources that cause the least pollution. It plans the use of land in the most effective way and prioritizes transportation options that take into account the needs and environmental priorities of the city residents. They minimize the negative impact of waste on climate change by reusing their waste as raw materials or energy using composting, recycling and/or other recovery methods (Yetano Roche et al., 2014).

The relative success of Turkey's cities in economic, social, and environmental dimensions is calculated with the evaluation of sustainability. Economic development positively reflects on the social environment and environmental quality. Social and environmental factors are vital for meeting the basic needs of people, improving living standards and for a safe future (Kou et al., 2018; Zhao et al., 2019; Mahmoudi et al., 2019; Sun et al., 2019). The concept of sustainable development, which provides economic, social and environmentally balanced and sustainable development, appears at this point. To understand how livable and sustainable a region is, there is a need for a model that consists of various factors and combines performances of different dimensions. In this context, the evaluation of the sustainability for Turkey's cities is considered as a Multi-Criteria Decision Making (MCDM) problem (Hwang & Yoon, 1981).

The heterogeneous structure of the sustainability evaluation includes a number of contradicting factors. Decision-makers (DMs) may struggle to express their views numerically since these numerical values are foreign to their way of thinking in everyday life. Furthermore, DMs can express their opinions more comfortably with words, instead of crisp numbers. This MCDM problem's uncertainty is solved via hesitant fuzzy linguistic term set (HFLTS) (Torra, 2010; Rodriguez et al., 2012).

In this study, the importance degree of the factors are computed by using the Hesitant Fuzzy Linguistic (HFL) Simple Additive Weighting (SAW) method (Chou et al., 2008). The HFL Multi-Attributive Border Approximation Area Comparison (MABAC) method (Sun et al., 2018) with fuzzy envelope technique (Liu & Rodriguez, 2014) is applied to evaluate Turkey's cities. This combined methodology is more sensitive to the change of attribute weight and has consistency for the formulation of the attribute. Thus, it is an effective and trustworthy decision-making approach, which is very suitable for dealing with complex MCDM problems for sustainability evaluation of Turkey's cities. This paper contributes to sustainability evaluation literature by proposing a novel integrated HFL MCDM methodology.

The study has been organized as follows. The second section presents the proposed research methodology. In Section 3, a case study is illustrated to demonstrate the effectiveness of the methodology. Finally, the last section concludes the study.

2 The Proposed Research Methodology

The proposed research approach in this study comprises of three steps:

Step 1. Development a framework for evaluating the sustainability of cities.

Step 2. Computation of the importance degree of the sustainability evaluation factors with the HFL SAW method.

Step 3. Evaluation of Turkey's cities by the HFL MABAC method according to the sustainability evaluation factors.

2.1 The Hesitant Fuzzy Linguistic Term Set

The uncertain environment frequently complicates choice difficulties encountered in the actual world. Linguistic information can aid in the management of uncertainty. Hesitant fuzzy sets were introduced for the first time in 2010 (Torra, 2010). A model presenting linguistic expressions via a set of HFLTS was introduced by Rodriguez et al. (2012) for enhancing the richness of linguistic flexibility in decision-making. In HFLTS, DMs utilize comparative linguistic expressions for making the evaluations for the criteria and alternatives.

An HFLTS, H_s, is an ordered finite subset of the consecutive linguistic elements of the set $S = \{s_0, ..., s_g\}$ (Rodriguez et al., 2012).

The upper bound H_{s+} and lower bound H_{s-} of the HFLTS are described as

$$H_{s+} = \max(s_i) = s_j \text{ , } s_i \in H_S \text{ and } s_i \leq s_j \ \forall_i \quad (1)$$

$$H_{s-} = \min(s_i) = s_j \text{ , } s_i \in H_S \text{ and } s_i \leq s_j \ \forall_i \quad (2)$$

The E_{GH} function is used to convert comparative linguistic term sets into HFLTS (Torra, 2010; Rodriguez et al., 2012).

The envelope of the HFLTS, *env(HS)*, is a linguistic interval with the upper bound (max) and the lower bound (min) as shown below (Liu & Rodriguez, 2014):

$$env(H_S) = [H_s^-, H_s^+], H_s^- \leq H_s^+ \quad (3)$$

2.2 The HFL SAW Method for Calculating the Weights of Factors

The HFL SAW method is used for smart watch evaluation and strategic renewable energy source selection in the literature (Büyüközkan & Güler, 2020). The steps of HFL SAW are explained next (Chou et al., 2008):

Step 1. DMs analyze the factors using linguistic terms (e.g. *"At least si", "At most si", "Between si and sj", "Greater than si", "Lower than si"*) provided in Table 1.

Table 1. Linguistic scale for HFL SAW and HFL MABAC (Beg & Rashid, 2013)

Linguistic term	Si	Abb.	Fuzzy Numbers
Perfect	s3	P	(0.83,1,1)
Very High	s2	VH	(0.67,0.83,1)
High	s1	H	(0.5,0.67,0.83)
Medium	s0	M	(0.33,0.5,0.67)
Low	s-1	L	(0.17,0.33,0.5)
Very Low	s-2	VL	(0,0.17,0.33)
None	s-3	N	(0,0,0.17)

Step 2. The fuzzy envelope transforms the matrix that consists of linguistic assessments of factors into HFLTS (Liu & Rodriguez, 2014).

Step 3. The fuzzy weights of the DMs are represented by the $\widetilde{\omega_t}$. The importance degrees of DMs (I_t) is computed as:

$$I_t = \frac{d(\widetilde{w_t})}{\sum_{t=1}^{k} d(\widetilde{w_t})}, t = 1,2, \dots, k \quad (4)$$

In this case, $d(\widetilde{w_t})$ represents the fuzzy weight's defuzzified value.

Step 4. Aggregated fuzzy weights of C_j, $\widetilde{W_j} = (a_j, b_j, c_j, d_j)$, are computed as:

$$\widetilde{W_j} = (I_1 \otimes \widetilde{W_{j1}}) \oplus (I_2 \otimes \widetilde{W_{j2}}) \oplus \dots \oplus (I_k \otimes \widetilde{W_{k1}}) \quad (5)$$

Here, $a_j = \sum_{t=1}^{k} I_t a_{jt}$, $b_j = \sum_{t=1}^{k} I_t b_{jt}$, $c_j = \sum_{t=1}^{k} I_t c_{jt}$, $d_j = \sum_{t=1}^{k} I_t d_{jt}$.

Step 5. The fuzzy weights are defuzzified. The defuzzified $\widetilde{W_j}$, shown as $d(\widetilde{W_j})$, is computed as:

$$d(\widetilde{W_j}) = \frac{1}{4} \left(a_j + b_j + c_j + d_j\right), where\ j = 1, 2, \dots, n \quad (6)$$

Step 6. The normalized weights (W_j) are computed as:

$$W_j = \frac{d(\widetilde{w_j})}{\sum_{j=1}^{n} d(\widetilde{w_j})}, j = 1,2, \dots, n \qquad (7)$$

$\sum_{j=1}^{n} W_j = 1$. Finally, the weight vector W=$(W_1, W_2, \dots, W_n)$ is established.

2.3 The HFL MABAC Method for Evaluating Cities

In the literature, the HFL MABAC method is used for patients' prioritization and strategic renewable energy source selection, healthcare waste treatment technology selection, strategic analysis of health tourism (Sun et al., 2018; Adar & Delice, 2019; Büyüközkan et al., 2021). The following are the steps of the HFL MABAC method:

Step 1. The DMs assessed alternatives using the linguistic scale shown in Table 1.

Step 2. Using fuzzy envelope, these linguistic expressions are converted into fuzzy numbers (Liu & Rodriguez, 2014).

Step 3. Fuzzy normalized matrix is determined as:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n} \qquad (8)$$

$$\tilde{r}_{ij} = \frac{y_{ij}-y_i^-}{y_i^+-y_i^-}, j \in B; \qquad (9)$$

$$\tilde{r}_{ij} = \frac{y_{ij}-y_i^+}{y_i^+-y_i^-}, j \in C; \qquad (10)$$

with $y_i^+ = \max\ (y_{1r}, y_{2r}, \dots, y_{mr})$ and $y_i^- = \min\ (y_{1l}, y_{2l}, \dots, y_{ml})$.

Here, B and C represent benefit and cost criterion sets respectively.

Step 4. Eq. (11) is used to generate the weighted normalized matrix.

$$\widetilde{U} = \left[\widetilde{U}_{ij}\right]_{m\times n} \qquad (11)$$

where $[\widetilde{U}_{ij} = \tilde{r}_{ij}$.wi + wi] and the weights of the components are denoted by wi.

Step 5. The approximate border area matrix is calculated by using Eq. (12).

$$\tilde{B} = \left[\prod_{j=1}^{m} U_{ij}\right]^{1/m} \qquad (12)$$

the total number of alternatives are denoted by m.

Step 6. The distances between the matrix components of alternative from the border area are calculated as follows:

$$\widetilde{D} = U - \tilde{B} \qquad (13)$$

Step 7. The ranking of alternatives is determined by adding the alternative distance from the border-approximation-area to the criterion function values for the alternatives. The total value of the criterion function of alternatives is computed by adding together all the matrix elements per row.

Step 8. The obtained values are defuzzified with Eq. (14) and ranked.

$$\mathrm{x_{ij}} = \frac{[(\mathrm{U_{x_{ij}}} - \mathrm{L_{x_{ij}}}) + (\mathrm{M_{x_{ij}}} - \mathrm{L_{x_{ij}}})]}{3} + \mathrm{L_{x_{ij}}} \qquad (14)$$

where $\tilde{x}_{ij} = \left(\mathrm{L_{x_{ij}}}, \mathrm{M_{x_{ij}}}, \mathrm{U_{x_{ij}}}\right)$.

3 Case Study

The evaluation of the sustainability of Turkey's cities is obtained by calculating the relative success of the economic, social, and environmental dimensions. This evaluation aims to contribute to the policy-making process for ensuring long-term and sustainable development and eliminating the problems of rapid urbanization and planning in Turkey.

In this study, a sustainability evaluation model is presented for Turkey's cities by utilizing the research report about this subject (MasterCard Worlwide & Boğaziçi University, 2011). According to this report, determined factors are as in Table 2.

Table 2. The sustainability evaluation factors (MasterCard Worlwide & Boğaziçi University, 2011)

Dimensions	Fi	Factors
Economic performance	F1	Transport and communication infrastructure
	F2	Access to domestic / foreign markets
	F3	Labor market
	F4	Human capital
	F5	Bank and financial services
	F6	Economic vitality and efficiency
	F7	R&D
Social performance	F8	Fight against poverty
	F9	Health
	F10	Social security
	F11	Public order and security
	F12	Education
	F13	Culture and art
	F14	Sheltering
	F15	The equality of woman and man
Environmental performance	F16	Natural assets
	F17	Environmental impact
	F18	Decontamination capacities
	F19	Energy

Turkey's top 8 cities that have metropolitan municipalities are evaluated within the scope of this model. These cities are Adana (A1), Ankara (A2), Bursa (A3), Gaziantep (A4), İstanbul (A5), İzmir (A6), Kayseri (A7), and Konya (A8). This model has been evaluated by DMs and they are industry experts with experience in this field.

In this study, there are three DMs to evaluate the sustainability evaluation factors and cities. All three DMs are sufficiently knowledgeable and experienced in the area of sustainability. The weights of the DMs are accepted as equal. DM1 has private sector experience about sustainable and environmental project management. DM2 is conducting academic and industrial research about sustainability. DM3 has public sector experience about smart and sustainable municipalities.

In the first part, the sustainability evaluation factors given in Table 2 are evaluated by DMs with respect to their experience and knowledge by using the linguistic scale shown in Table 1. Table 3 shows the DMs' decision matrix.

Table 3. Decision matrix for the sustainability evaluation factors

Ci	DM1	DM2	DM3
C1	At least H	Greater than M	Between M and VH
C2	Between M and VH	Lower than M	Between L and M
C3	Between M and VH	Between L and M	Lower than M
C4	At least H	Between L and M	Between M and VH
C5	Between VL and L	Lower than M	Between L and M
C6	Between L and M	Between M and VH	Between M and VH
C7	Between M and VH	Between L and M	Between L and M
C8	Lower than M	Between L and M	Between L and M
C9	Greater than M	At least H	At least H
C10	Between M and VH	Between L and M	Between L and M
C11	Between M and VH	Lower than M	Between L and M
C12	Between M and VH	Greater than M	Between M and VH
C13	Lower than M	At most L	Between L and M
C14	Lower than M	Between L and M	At most L
C15	Between L and M	Between M and VH	Between L and M
C16	Between VL and L	Lower than M	Between M and VH
C17	Between L and M	Lower than M	Between L and M
C18	Between VL and L	Lower than M	Lower than M
C19	Lower than M	Between L and M	Between M and VH

Considering the DMs' evaluation, steps of HFL SAW are employed and weights of factors are computed. These weights are given in Table 4.

Table 4. The weights of sustainability evaluation factors

Fi	Aggregated Fuzzy Weights	Defuzz. Weights	Norm. Weights	Rank
F1	(0.443,0.613,0.777,0.943)	0.694	0.081	2
F2	(0.167,0.333,0.500,0.667)	0.417	0.049	9
F3	(0.167,0.333,0.500,0.667)	0.417	0.049	9
F4	(0.333,0.500,0.667,0.833)	0.583	0.068	4
F5	(0.057,0.223,0.387,0.557)	0.306	0.036	16
F6	(0.277,0.443,0.613,0.777)	0.528	0.062	5
F7	(0.223,0.387,0.557,0.723)	0.473	0.055	6
F8	(0.113,0.277,0.443,0.613)	0.362	0.042	13
F9	(0.500,0.670,0.830,1.000)	0.750	0.088	1
F10	(0.223,0.387,0.557,0.723)	0.473	0.055	6
F11	(0.167,0.333,0.500,0.667)	0.417	0.049	9
F12	(0.387,0.557,0.723,0.887)	0.638	0.075	3
F13	(0.057,0.223,0.387,0.557)	0.306	0.036	16
F14	(0.057,0.223,0.387,0.557)	0.306	0.036	16
F15	(0.223,0.387,0.557,0.723)	0.473	0.055	6
F16	(0.110,0.280,0.443,0.610)	0.361	0.042	15
F17	(0.113,0.277,0.443,0.613)	0.362	0.042	13
F18	(0,0.170,0.330,0.500)	0.250	0.029	19
F19	(0.167,0.333,0.500,0.667)	0.417	0.049	9

In the second part, DMs are evaluated alternative cities using the linguistic scale illustrated in Table 1. As an example, according to C1, DMs use "Between L and M" expression for A1, "Between M and VH" expression for A2, "At most M" expression for A3, "Between VL and N" expression for A4, "At least M" expression for A5, "Between M and VH" expression for A6, "At most L" expression for A7, "At most L" expression for A8.

Equations are used to translate linguistic expressions to HFLTS, which are subsequently converted to fuzzy numbers. The evaluation matrix is normalized using Eqs. (8)-(10) and the weighted normalized matrix is constructed with Eq. (11).

The approximate border area matrix and distances between the matrix components of the alternative from the border area are calculated with Eqs. (12) and (13). Finally, these values are defuzzified and the evaluation and ranking of cities are shown in Table 5.

As a result, Ankara (A2) has become the most sustainable city in Turkey among the eight alternatives with the final performance value. According to results in Table 4, the other cities are ranked as İstanbul (A5), İzmir (A6), Bursa (A3), Adana (A1), Konya (A8), Kayseri (A7), and Gaziantep (A4), respectively.

According to the evaluation model, Ankara is Turkey's leading city, especially in terms of social and quality of life. In terms of future potentials, it has a potential as much as Turkey's average in the field of trade and industry. Transportation, living conditions and security are among the areas where it is advantageous.

Table 5. The weights of sustainability evaluation factors

Alternatives	Si			Defuzz	Rank
Adana (A1)	-0.543	-0.033	0.484	-0.031	5
Ankara (A2)	-0.317	0.183	0.643	0.170	1
Bursa (A3)	-0.487	0.004	0.501	0.006	4
Gaziantep (A4)	-0.709	-0.216	0.312	-0.204	8
İstanbul (A5)	-0.338	0.168	0.643	0.158	2
İzmir (A6)	-0.385	0.125	0.614	0.118	3
Kayseri (A7)	-0.564	-0.062	0.454	-0.057	7
Konya (A8)	-0.574	-0.061	0.468	-0.055	6

Alternative cities are assessed using HFL COPRAS and HFL TOPSIS to examine the robustness of the HFL MABAC method's outcomes. The solutions from all methods for sustainability evaluation give similar results. The most sustainable city is again Ankara (A2). Furthermore, the order of the second alternative is same. These techniques are similar in approach and are both distance-based, however the MABAC technique is newer and more practical when compared to others. In comparison to the results of other MCDM approaches, this integrated HFL MABAC technique yields extremely consistent end values.

4 Conclusion

Although it is not a very new perspective to not only think about today but also tomorrow, this issue has become an issue that is more emphasized with the concept of sustainability. Development-oriented policies have left their place to sustainable development. At this point, instead of central policies, regional-specific policies come to the fore. Here, on the other hand, city-specific plans, policies and practices should be put into practice, as a departure from the private to the general will make things easier.

The study aims to measure the relative success of Turkey's cities in the economic, social, and environmental dimensions, and to evaluate their sustainability. For such an evaluation, a sustainability index was made using objective data and the degree of sustainability of cities was calculated. The evaluation of Turkey's cities' sustainability is viewed as an integrated HFL MCDM problem in this study. First, the HFL SAW technique is used to compute factor weights. The HFL MABAC approach is then used to evaluate Turkey's cities. An application is shown to demonstrate the efficacy of the approach, and the findings of this investigation are presented. The most sustainable city is found as Ankara (A2).

The problem can be handled in future research by using aggregation operators for group decision-making to aggregate DM assessments. As a second perspective, both the HFL SAW and HFL MABAC techniques might be used with various fuzzy set extensions such as intuitionistic and Pythagorean.

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