Evaluation of Potential Locations for Hydropower Plants by Using a Fuzzy Based Methodology Consists of Two-Dimensional Uncertain Linguistic Variables

ihsan kaya (ihkaya@yildiz.edu.tr)
Gürkan Işık
Ali Karaşan
Fatma Kutlu Gündoğdu
Hayri Baraçlı

Research Article

Keywords: Location Selection, hydropower plant, hesitant fuzzy sets, Cognitive Mapping, DEMATEL, TOPSIS, z-number

Posted Date: May 18th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1665911/v1

JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 36, XXX-XXX (2022)
DOI: 10.6688/JISE.20200X_36(X).00XX

Evaluation of Potential Locations for Hydropower Plants by Using a Fuzzy Based Methodology Consists of Two-Dimensional Uncertain Linguistic Variables

İHSAN KAYA[1], GÜRKAN IŞIK[2], ALİ KARAŞAN[1], FATMA KUTLU GÜNDOĞDU[3] AND HAYRİ BARAÇLI[1]

[1]*Department of Industrial Engineering, Yildiz Technical University, İstanbul, Turkey*

[2] *Business Development Department, Valuable Touch Energy Services, 54050, Sakarya, Turkey*

[3]*Department of Industrial Engineering, National Defence University Turkish Air Force Academy, İstanbul, Turkey.*

Corresponding Author's E-mail: ihkaya@yildiz.edu.tr

Hydropower is one of the most efficient renewable energy sources for the sustainability of the environment if the plant location is well decided. The plant location should satisfy different criteria emerged by a wide range of criteria, consisting of law, environment, and the expectations of the investors and residents. Some of these criteria can be conflicting. Some of them may also be in a relationship with each other. Moreover, they may be evaluated in a system that contains uncertainty consisting of a lack of information, impreciseness in the data, and human hesitancy. These aspects can be a powerful effect on the location selection of the hydropower plants and are considered in mathematical formulations. So, the problem can be considered as a multi-criteria decision-making (MCDM) problem under uncertainty. In this study, by considering the types of uncertainties, impreciseness of the available data, and hesitancy of the experts, an integrated MCDM methodology consisting of DEMATEL, cognitive mapping, and TOPSIS methods has been extended based on hesitant fuzzy z-numbers. Then the proposed methodology has been applied for the evaluation of potential locations for hydropower plants in Turkey. For this aim, a hierarchical structure consisting of twenty-nine criteria and four alternative locations has been determined for the assessment by combining literature analysis and expert knowledge. In the first stage, the criteria "Availability of Water", "Annual flow", "Technology", "Capacity", and "Annual energy production" have been demonstrated as the most influential criteria for location selection. Then, based on the z-number fuzzy TOPSIS method, the most appropriate alternative for the construction location has been determined in Turkey. The findings have been checked in terms of validation and flexibility of the given decisions by applying sensitivity and comparative analyses.

Keywords: Location Selection**,** hydropower plant, hesitant fuzzy sets, Cognitive Mapping, DEMATEL, TOPSIS, z-number

1. INTRODUCTION

Hydropower is one of the best renewable energy source alternatives on both large and small scale because of its many advantages, such as high response capability and demand fluctuations. For this reason, the literature widely focuses on micro, small and large hydropower plant projects. However, most analyses that only consist of technical and economic aspects are conducted to determine the highest rate of electricity production [1]. The correct location is utterly critical to improving the performance of hydropower plants. It should be designed an MCDM problem to analyze for alternative locations deeply. There are many essential criteria for the success of hydropower plants, and they have been categorized as qualitative and quantitative in terms of measurable data. While considering these criteria, there can be uncertainty during the evaluations due to the lack of information, imprecision, and human hesitancy. It is not easy to overcome these types of uncertainties simultaneously in a model that uses crisp numbers. To be able to reflect such uncertainties while modeling the problem, the ordinary fuzzy set theory (FST) was developed by Zadeh [2]. However, FST does not consider the situations in which the decision-maker has difficulty making a single choice. Torra [3] proposed hesitant fuzzy sets (HFS) to deal with this issue. HFS allows assigning more than one membership degree for an element in a set. Instead of numeric membership degrees of an element, Rodriguez et al. [4] proposed the hesitant fuzzy linguistic terms (HFLTS) to enrich linguistic expressions that are more suitable for people's thinking and deciding structures. In this way, experts could use more flexible expressions when comparing alternatives or evaluating processes. Another limitation of FST is the reliability of the information, which is a problem that arises from the hesitancy of the human being. To formulate this type of uncertainty in the mathematical operations, z-numbers have been proposed as a new fuzzy concept by Zadeh [5].

This paper aims to decide the most appropriate plant location alternative by evaluating the critical criteria for the success of the hydropower plants by considering the constructed MCDM context. Based on that, a methodology involving HFLTS has been extended with z-numbers to make more flexible assessments [6]. The proposed methodology consists of three calculation phases, DEMATEL, cognitive mapping, and TOPSIS, to evaluate the hydropower plant location alternatives. Before the calculations, the problem environment is designed based on the literature review and expert knowledge. Then, for the first phase of the calculations, an extended DEMATEL method based on hesitant fuzzy z-numbers has been applied to determine the dependencies between the determined critical criteria for the success of hydropower plants. Then, the fuzzy cognitive map based on z-number has been used to determine the most influential criteria for the success of a hydropower plant since it allows grading about the level of causality so that linguistic terms can represent the weights of the interconnections [7]. Finally, the most appropriate location alternative has been determined by using the z-number fuzzy TOPSIS method. The obtained results of the methodology have also been analyzed in terms of validation and flexibility. Through that, sensitivity and comparative analyses have been conducted for discussions. Through that, the contribution of the paper to the literature can be listed as follows: (*i*) A comprehensive decision-making structure consisting of not only technological and economic characteristics, but also social and environmental aspects have been constructed for the decision-making process to better handle the problem with a wide range of perspectives. (*ii*) Since the decision-making process involves expert knowledge and evaluations for the solution, it is crucial to consider their hesitancy while evaluating the problem. By conducting z-number concept, reflecting this characteristic to the mathematical operations is enabled for effective results. Therefore, the decision-making procedure involves the impreciseness of the data and the hesitancy of the decision-makers simultaneously. (*iii*) By involving dependencies of the evaluation criteria, the proposed methodology offers flexibility to represent both influences of the criteria among themselves and their magnitudes of the relations for the problem solution. Based on that, a comprehensive evaluation procedure deals with the selection of the most appropriate hydropower plant.

The rest of this paper has been organized as follows: A literature analysis to determine the critical factors of hydropower plants have been presented in Section 2. The proposed fuzzy-based methodology and its basic concepts are briefly summarized in Section 3. An application consisting of problem definition, obtained results, sensitivity analysis, and comparative analysis for hydropower plant location selection is detailed in Section 4. The paper ends with the obtained results and future research suggestions explained in Section 5.

2. A STRUCTURAL ANALYSIS FOR LOCATION SELECTION

Selection of the best facility location has vital importance on the success of the investments. Improper site selection may fail because of increased installation and operating costs, decreased productivity, and conflicts with residents and the local government. This decision should be made by considering multiple actors having different expectations, such as investors, workers, residents. It is hard to evaluate the actors' expectations simultaneously since there may be conflicts between the actors. Based on that, criteria related to policy aspects, social conditions, and environmental factors directly relate to human judgments and include uncertainties. Additionally, it is not easy to evaluate the criteria based on vagueness. One of the most popular techniques is FST that can successfully model uncertainties, and it has been widely employed in the literature to model such variations for the facility location problem. The facility location problem has also been studied in the literature for hydropower plants. However, there are limited studies in the literature on fuzzy modeling of the hydropower plant location problem. Saracoglu [14] adopted DEMATEL with fuzzy linguistic variables, Abdullah & Aslam [15] modeled the location problem based on an intuitionistic cubic fuzzy set, Shimray et al. [16] presented a model using a neural network and fuzzy approaches, Chien et al. [17] solved the problem using fuzzy AHP and TOPSIS. Although the nature of the hydropower plant location problem necessitates considering human-related fuzziness factors, none of the mentioned studies consider more complex fuzziness caused by human-related factors such as the imprecision due to lack of information and unreliable decisions based on the experts' or decision makers' hesitancy. Through that, in this study, integrated multi-criteria decision-making (MCDM) methodology is suggested and extended with hesitant fuzzy-z numbers to deal with mentioned uncertainties based on human-related factors.

For this aim, a hierarchical structure based on main and sub-main criteria with alternatives has been constructed. The main and sub-criteria for location selection for hydropower plants have been categorized based on a literature review. The alternative locations have been determined based on the annual report of the DSI in Turkey and labeled as "Alternative #" [25]. Based on the literature analysis and experts' ideas, the decided criterion set is presented in Fig. 1.

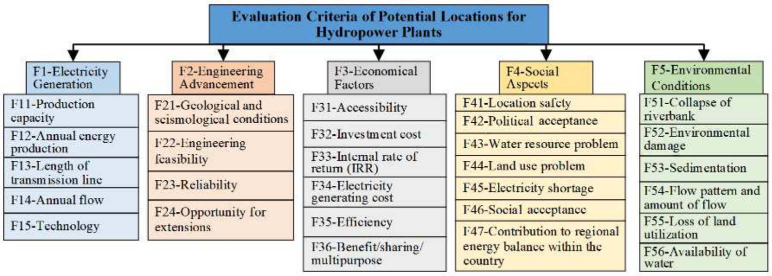

Fig. 1. The Related Criteria for Location Selection of Hydropower Plant

3. A FUZZY-BASED METHODOLOGY FOR THE EVALUATION

In this paper, an integrated MCDM methodology consisting of fuzzy z-DEMATEL, fuzzy z-Cognitive mapping, and fuzzy z-TOPSIS techniques is employed to evaluate potential locations for hydropower plants for Turkey. In the following sub-sections, the preliminaries for the applied techniques together with their steps are presented.

3.1 Hesitant Fuzzy Z Number Based DEMATEL

Decision-Making Trial and Evaluation Laboratory (DEMATEL) is an efficient approach used to address the internal dependencies of complex systems. It enables the representation of the relationship of criteria as cause and effects and transforms them into a visual structural model [18] [19]. Moreover, by establishing interrelationships between the criteria, it creates a pattern to causal relationships through the cause-effect relationship diagram [20] [21]. Since the evaluation criteria of the hydropower plant selection problem have dependencies among themselves, which results in conflicting effects to the selection process, it is important to involve this feature in the solution process for a better result. Since the hesitant fuzzy z number-based DEMATEL has the ability to determine these dependencies, it is used in our methodology. To address the uncertainty appropriately, in this study, the hesitant z-concept is conducted for the calculations. The constructed linguistic scale for the membership functions is given in Fig. 2. For the assignment of the hesitancy of the experts while determining the membership functions, constructed linguistic scale for the reliability functions is presented in Fig. 3.

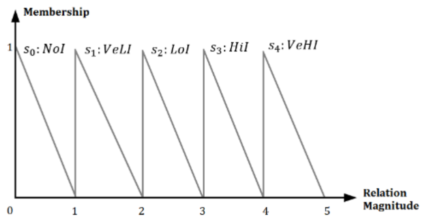

Fig. 2. Constructed linguistic scale for the membership functions (DEMATEL)

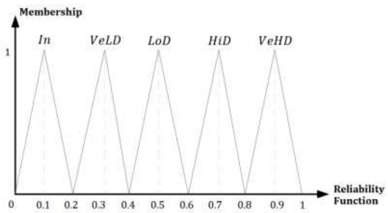

Fig. 3. Constructed linguistic scale for the reliability functions

The steps of the approach are presented in Algorithm 1.

Algorithm 1: Hesitant fuzzy z-DEMATEL

Input: *Evaluation of the experts' consensus* (x_{ij})
Output: *Relationship matrix of the criteria.*

Begin

Step 1: *Assign the linguistic terms for the preciseness (Based on Figure 2)*

Step 2: *Assign the linguistic terms for reliability (Based on Figure 3)*

Step 3: *Aggregate the membership functions by using the OWA operator*

Step 4: *Utilize the reliability function* (α) *with the aggregated membership function to obtain fused fuzzy numbers* $(\tilde{A})$ *by using the following equation:*

$$\alpha = \frac{\int x\mu_{\tilde{B}}(x)dx}{\int \mu_{\tilde{B}}(x)dx}$$
$$\tilde{A}(x_{ij}) = \tilde{y}^{\alpha}$$
$$\text{where } x_{ij} = (l_{ij}^n, ml_{ij}^n, r_{ij}^n).$$

Step 5: *Convert fused fuzzy numbers to crisp values by using the following equations:*

$$xr_{ij}^n = \left(r_{ij}^n - minl_{ij}^n\right)/\Delta_{min}^{max}$$
$$xm_{ij}^n = \left(ml_{ij}^n + mr_{ij}^n/2 - minl_{ij}^n\right)/\Delta_{min}^{max}$$
$$xl_{ij}^n = \left(l_{ij}^n - minl_{ij}^n\right)/\Delta_{min}^{max} \text{ where } \Delta_{min}^{max} = maxr_{ij}^n - minl_{ij}^n.$$
$$xrs_{ij}^n = xr_{ij}^n/\left(1 + xr_{ij}^n - xm_{ij}^n\right)$$
$$xls_{ij}^n = xm_{ij}^n/\left(1 + xm_{ij}^n - xl_{ij}^n\right)$$
$$x_{ij}^n = \left[xls_{ij}^n\left(1 - xls_{ij}^n\right) + xrs_{ij}^n \times xrs_{ij}^n\right] / \left[1 - xls_{ij}^n + xrs_{ij}^n\right]$$

Step 6: *Construct the direct relationship matrix*(X).

Step 7: *Normalize the fuzzy direct influence matrix to obtain a normalized fuzzy direct influence matrix*(A).

$$k = min\left\{1/\max_i\left(\sum_{j=1}^n a_{ij}\right), 1/\max_j\left(\sum_{i=1}^n a_{ij}\right)\right\} \text{ and } A = k \times X.$$

Step 8: *Generate the fuzzy total influence matrix*(T).

$$T = A_l \times (I - A)^{-1} \text{ where I identity matrix and T total influence matrix.}$$

Step 9: *Calculate min, max, and arithmetic averages*

of the values of the total relation matrix.
Step 10: *Determine the threshold value by multiplying the min by 0.2, the max by 0.3, and the average by 0.5.*
Step 11: *Compare each value in the fuzzy total relation matrix with the threshold; if the value is greater than the threshold, there is a relationship. Otherwise, no relationship is concluded.*
End

3.2 Hesitant Fuzzy Z number based Cognitive Mapping

Tolman introduces cognitive maps for investigating the behavioral symptoms of the rats for a certain path to reach the food and the connection of this learning process with the human behaviors [22]. For more complex problems, Kosko introduced conventional fuzzy cognitive maps (FCMs) to increase data reflection and the ability to represent the uncertainty of the cognitive maps [23]. Based on the mentioned advantages, we applied cognitive maps with their z-number theory with hesitant fuzzy sets to determine the most influential criteria for the location selection of a hydropower plant with respect to constructed context. The constructed scale for the membership functions is given in Fig. 4. The terms for membership functions can also be in negative forms since a criterion may affect the other adversely. Moreover, Fig. 3 is used for the reliability functions to express the hesitancy of the experts. The process of the hesitant fuzzy z-cognitive map is given in Algorithm 2.

Algorithm 2: Hesitant fuzzy Z-cognitive map

Input: *number of criteria* $(i = 1, \dots, n)$, *number of iterations* $(t = 1, \dots, k)$, *magnitude of the relation* (w_{ji}^{μ}), *reliability of the decision* (w_{ji}^{r}).
Output: *weights of the criteria.*
Begin
Step 1: *Assign the linguistic terms for the preciseness (Based on Figure 4)*
Step 2: *Assign the linguistic terms for reliability (Based on Figure 3)*
Step 3: *Assign the direction of the effects* $(+)/(-)$ *to construct a direction matrix*
Step 4: *Aggregate the membership functions by using the OWA operator*
Step 5: *Determine the initial vector* (I^k)
Step 6: *Iterate the following convergence functions until each of the compared models is converged. (For the convergence, the sigmoid function is conducted.)*

$$s_i^{(t+1)} = f\left(s_i^{(t)} + \sum_{\substack{j=1 \\ j\neq i}}^{n} \left(s_j^{(t)} \cdot w_{ji}^{(\mu)(t)} \cdot w_{ji}^{(r)(t)}\right)\right)$$

Step 7: *Aggregate the results of the decision-makers*
Step 8: *Prioritize the criteria*
End

3.3. Fuzzy Z Number Based TOPSIS Method

The fuzzy Z number-based TOPSIS method is conducted to prioritize the hydropower plant locations according to the constructed decision matrix. Since TOPSIS is a distance-based ranking method using evaluations of the alternatives with respect to criteria, it is suitable to apply it for a hydropower plant location problem. The pseudo-code of the Z-numbers fuzzy TOPSIS (z-TOPSIS) method is given in Algorithm 3. The constructed scale for the assessments is given in Fig. 5.

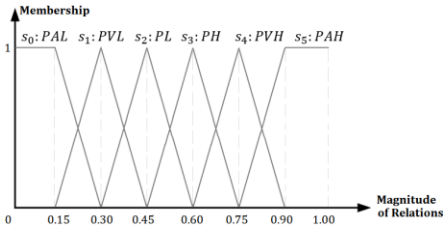

Fig. 4. Constructed linguistic scale for the membership functions (Cognitive Map)

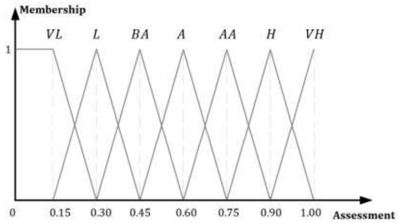

Fig. 5. Constructed linguistic scale for the membership functions (TOPSIS)

DOI: 10.6688/JISE.20200X_36(X).00XX

Algorithm 3: Fuzzy Z-TOPSIS [24]

Input: *n: number of criteria, m: number of alternatives, k: number of experts, w_n: weight of the criteria*
Output: *Ranking of the alternatives*
Begin
  For $i = 1{:}k$ ***do***
  Step 1: *Input linguistic decision matrices ⇒ (Based on Fig. 3 and Fig. 5)*
  Step 2: *Convert linguistic terms into corresponding z-numbers* $\left(C = (\tilde{c}^k{}_{ij})_{n\times m}\right) \Rightarrow$ *(Based on Fig. 3 and Fig. 5) where* $\tilde{c}^k{}_{ij} = \langle\left[\mu_{ij}^{l^k}, \mu_{ij}^{m^k}, \mu_{ij}^{r^k}\right], \left[r_{ij}^{l^k}, r_{ij}^{m^k}, r_{ij}^{r^k}\right]\rangle$
  Step 3: *Fuse the membership and reliability functions using the following function*
$$\int \left(\mu_{ij}(x)\right) \times \left(r_{ij}\right) dx$$
  End for
  Step 4: *Aggregate fused decision matrices to obtain collective z-number decision matrix* $C = (\tilde{c}_{ij})_{n\times m}$ *and* $\tilde{r}_{ij} = \left\langle \sum \frac{\mu_{ij}^{l}(x)}{k}, \frac{\mu_{ij}^{m}(x)}{k}, \frac{\mu_{ij}^{r}(x)}{k} \right\rangle$
  Step 4: *Compute weighted collective z-number decision matrix* $\left(R^* = (\tilde{r}_{ij}^*)_{n\times m}\right)$
$$\tilde{r}^*{}_{ij} = \textstyle\sum_{i=1}^{n} w_i \tilde{r}_{ij}, \quad j = 1,2,\dots,m$$
where $\tilde{r}^*{}_{ij} = \langle \mu_{ij}^{l^*}, \mu_{ij}^{m^*}, \mu_{ij}^{r^*} \rangle$.
  Step 5: *Determine z-number positive ideal solutions* (O^+)
$O^+ = (\tilde{r}_1^+, \tilde{r}_2^+, \dots, \tilde{r}_m^+)$ *where* $\tilde{r}_i^+ = \langle \mu_{ij}^{l^+}, \mu_{ij}^{m^+}, \mu_{ij}^{r^+} \rangle$ *and* $\mu_{ij}^{l^+} = \mu_{ij}^{m^+} = \mu_{ij}^{r^+} = 1$.
  Step 6: *Determine z-number negative ideal solutions* (O^-)
$O^- = (\tilde{r}_1^-, \tilde{r}_2^-, \dots, \tilde{r}_m^-)$ *where* $\tilde{r}_i^- = \langle \mu_{ij}^{l^-}, \mu_{ij}^{m^-}, \mu_{ij}^{r^-} \rangle$ *and* $\mu_{ij}^{l^-} = \mu_{ij}^{m^-} = \mu_{ij}^{r^-} = 0$.
  Step 7: *Compute Euclidean distance of each alternative to* O^+ (S_{j^+})
  For $j = 1{:}m$ ***do***
$$S_{j^+} = \frac{1}{3}\sum_{i=1}^{n}\left[\left(\mu_{ij}^{l^+} - \mu_i^{l^*}\right)^2 + \left(\mu_{ij}^{m^+} - \mu_i^{m^*}\right)^2 + \left(\mu_{ij}^{r^+} - \mu_i^{r^*}\right)^2\right]$$
  End for
  Step 8: *Compute Euclidean distance of each alternative to* $O^-(S_{j^-})$
  For $j = 1{:}m$ ***do***
$$S_{j^-} = \frac{1}{3}\sum_{i=1}^{n}\left[\left(\mu_{ij}^{l^-} - \mu_i^{l^*}\right)^2 + \left(\mu_{ij}^{m^-} - \mu_i^{m^*}\right)^2 + \left(\mu_{ij}^{r^-} - \mu_i^{r^*}\right)^2\right]$$
  End for
  Step 9: *Calculate the relative closeness* $\left(\zeta(r_j)\right)$
  For $j = 1{:}m$ ***do***
$$\zeta(r_j) = \frac{D\left(r_j^*, O^-\right)}{D_{max}\left(r_j^*, O^-\right)} - \frac{D\left(r_j^*, O^+\right)}{D_{min}\left(r_j^*, O^+\right)}$$
  End for
  Step 10: *Rank the alternatives with respect to* $\zeta(r_j)$
End

3.4 The Proposed Methodology

In this paper, the mentioned methods are utilized for an integrated decision-making methodology to analyze the critical criteria for the success of a hydropower plant and then applied for pre-determined alternative locations for the selection. Since the constructed linguistic scales have been used for the evaluations with respect to experts' knowledge, the fuzzy sets theory is applied to extend proposed techniques to represent the linguistic terms in the mathematical operations during the solution process. For the first phase of the methodology, a list of the criteria for the success of a hydropower plant has been determined based on a literature review. In the second phase, an extended DEMATEL method based on hesitant fuzzy z-numbers has been conducted to determine the dependencies between the criteria. Based on the outcomes of the extended DEMATEL method, the cognitive map structure is constructed. Through the constructed structure, experts assigned linguistic terms to the arcs between the criteria to demonstrate the level of their relations. Based on the obtained cognitive map, a weight matrix has been constructed. Finally, the iterations are run until the weight matrix is converged. The final weights of the criteria are calculated to prioritize them. For the prioritization of the alternatives, a decision matrix is constructed based on the consensus of experts. The decision matrix and weight of the criteria are used as inputs of the fuzz Z-number TOPSIS method. Through the calculations, the score and rank of the alternatives are obtained. The flowchart of the applied methodology is given in Fig. 6 as follows:

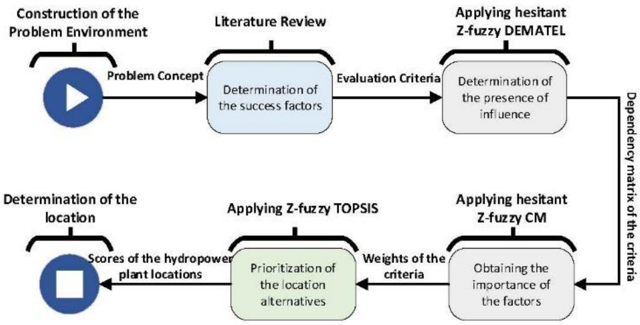

Fig. 6. Flowchart of the proposed methodology

4. AN APPLICATION

In this section, a new integrated fuzzy-based decision-making methodology is applied to select the hydropower plant location by considering impreciseness in the data and the hesitancy of the experts. Through that, a decision-making structure is created by considering both literature review and expert knowledge. The evaluation of the experts is realized as a consensus-based assessment process and involved in mathematical calculations.

4.1. Problem Definition

Hydropower plants are important clean energy sources for Turkey since they are environmentally friendly, revitalize the economic and social structure in rural areas, carry low potential risks and respond to sudden demand changes. For this reason, hydroelectric energy investments are continued with the cooperation of the State-Private sector to improve the hydroelectric potential. Moreover, governmental incentives and direct investments are increasingly realized through Turkey, where the private sector is insufficient.

In Turkey, annual electricity consumption per capita is at the level of 3,300 kWh/year. To fulfill this demand, Turkey’s investment in energy generation is continuously increasing year by year. For one of the energy generation sources, hydropower energy plants, the directorate-general for state hydraulic works is the only authorized institution to develop the hydroelectric potential and make it available to Turkey's national economy. The theoretical hydroelectric potential in Turkey is calculated as 433 billion kWh/year, and the technically usable potential is calculated as 216 billion kWh/year. Of the 216 billion kWh/year portion of Turkey's technically assessable hydropower energy potential, the technical, economic, environmental, and socially feasible portion is 180 billion kWh/year. The part of the total feasible potential that is operational is 108 billion kWh/year by the end of 2020 [25]. The investments and constructions are increasing day by day to meet the addressing aim of the Turkish government.

Therefore, in this study, four possible hydropower energy source locations are evaluated for prioritization by considering a wide range of criteria. The criteria are given in Fig. 1, which consists of both technical and social features. The evaluation of the decision-making process for the problem solution is carried out with an expert consensus, which consists of four experts with the following features: two of the experts are the mechanical engineers from the dams in Istanbul named Buyukcekmece and Elmali-2. The other two are the environmental engineers in ISKI (Istanbul Water and Sewerage Administration). For the evaluation procedure, two assessment parameters are obtained from the expert consensus for each of the evaluations. The first one is the measurement of the evaluation, which is obtained by using membership function scales in linguistic forms. The second parameter is the reliability of the measurement of the evaluation, which is also called hesitancy, and it is collected by using the constructed reliability scale in linguistic forms.

4.2. The Obtained Results

For the determination of the critical criteria for the success of the hydropower plants, a comprehensive study is conducted. A consensus is constructed, which consists of four experts from the field of renewable energy sources. For the first phase of the study, conceivable critical criteria are determined by reviewing the literature. Then, to determine the presence of the influence between the criteria, the hesitant fuzzy z-DEMATEL method is conducted. For an illustration, the Effect of the subcriterion,"F12-Annual energy production", on the subcriterion, "F11- Capacity", is given as follows: The consensus assigned "Between Low Influence" and "Very High Influence" membership functions with "Low Determinacy" for the evaluation. Then, the OWA operator, an effective technique for aggregating linguistic terms, is conducted to obtain aggregated membership functions. The aggregated value is in trapezoidal fuzzy form and equals (0, 0.889, 1.111, 3). By the way, the corresponding triangular fuzzy number (TFN) for the reliability function, Low Determinacy, is equal to (0.4, 0.5, 0.6). This procedure is applied for each of the evaluations in the hesitant fuzzy z-DEMATEL technique. Then, for the same example, as a next step, the membership and reliability functions are fused as given in Step 4 of Algorithm 1 to obtain the following value: (0, 0.623, 0.786, 2.121). Then, Step 5 of the Algorithm 1 is processed to construct a direct relationship matrix. For the illustrative values, the corresponded evaluation is equal to 0.309. After that, the normalization formula is applied, which is given in Step 7 of Algorithm 1. For the normalization step, k value is calculated as 0.0594. After the matrix calculations, the threshold value is obtained as 0.0716. Through Algorithm 1, 241 relations are determined. As the next phase, the hesitant fuzzy z-cognitive map is conducted to determine the magnitude of the relations, which yields the importance of the evaluation criteria. For the determination of the weight vector, the same consensus evaluated the relations.

For the illustration, for evaluating the influence magnitude, the subcriterion "F21-Technology" to the subcriterion "F11-Capacity" is considered. The evaluation consists of "Positively Absolutely High Influence Magnitude" membership function and "Very High Determinacy" reliability function. Since the evaluation consists of only one membership function, the OWA operator does not need to be applied. Then, (0.75, 0.9, 1) triangular fuzzy number for membership function and (0.8, 0.9, 1) TFN of reliability function are assigned as the corresponding values of the linguistic terms. After that, Step 6 of Algorithm 2 is conducted for the conversion. After eight iterations, the weight matrix is converged. As a result, the subcriteria "F56- Availability of Water", "F14-Annual Flow", "F21-Technology", "F11-Capacity", "F12-Annual Energy Production" are determined as the most influential criteria among the other based on the constructed context, respectively [26]. As the next phase, the fuzzy z-TOPSIS method is applied to determine the most appropriate location among the four alternatives for the construction. Based on the calculations, the results are obtained, as shown in Table 1. Based on the calculations, A1 is determined as the most appropriate location for constructing the hydropower plant.

Table 1. Results of the application and Compared Technique

	i) The application				**(ii) The compared technique**			
	A1	**A2**	**A3**	**A4**	**A1**	**A2**	**A3**	**A4**
Distance to PIS	19.45	19.52	19.45	19.48	19.04	18.98	18.91	19.03
Distance to NIS	8.887	8.869	8.803	8.866	8.841	8.813	8.714	8.799
Coefficient	0	-0.006	-0.009	-0.004	-0.007	-0.007	-0.014	-0.011
Rank	1	3	4	2	1	2	4	3

4.3. A Comparative Analysis

A comparative analysis is carried out to show the advantage of the proposed methodology based on 2-dimensional uncertainty representation. For that, the ordinary fuzzy TOPSIS method is used. For the decision matrix, the same matrix related to the membership function is used. The hesitancy evaluations, represented as the reliability function, are neglected since the ordinary fuzzy concept considers that all evaluations are carried out with no hesitancy. Therefore, this sub-section aims to show the effectiveness of hesitancy of the experts for the calculations. Based on the steps of the ordinary fuzzy TOPSIS method, the revised results are obtained, as in Table 1(ii).

As seen in Table 1(ii), the most and worst appropriate alternatives remain the same, A1 and A4, but other ranks are changed. When the decision matrix of the application is analyzed, it is seen that the total reliability of A2 is worse than A4. If the reliability functions are weighted with respect to criteria weights, the values are obtained for alternatives as follows: (0.45, 0.55, 0.65), (0.43, 0.53, 0.63), (0.42, 0.52, 0.62), and (0.48, 0.58, 0.68), respectively for A1, A2, A3, and A4.

Based on this results, it is seen that the total reliability of A2's evaluations is worse than A4's evaluations. Since the membership functions of the A2's evaluations are better than A4 (as seen in results given in Table 1(ii)), the effect of hesitancy greatly impacts the results.

When humans' nature and evaluations are considered, the importance of the hesitancy for subjective evaluations can be demonstrated based on these two results. Through that, it is important for the systems where hesitancy exists to reflect them in the mathematical operations. Therefore, fuzzy z-number is an efficient way of reflecting them and is a concept that generates meaningful results.

4.4. Sensitivity Analysis

To show the flexibility of the given decisions, a sensitivity analysis procedure is conducted. To be able to do that, five cases with a total of 10 scenarios are simulated, and the results are analyzed. For this aim, weights of the subcriteria "F56- Availability of Water", "F14-Annual flow", "F21-Technology, F11-Capacity", "F12-Annual energy production" are changed, and new results are observed. Based on the calculations, the results are obtained, as shown in Fig. 7. The initial section is the results of the application, and other variations represent the ranks of the alternatives based on the weights of the mentioned criteria, which are 0.1 and 0.9, respectively.

As seen in Fig. 7, “F56- Availability of Water” criterion is the most influential one for Alternative 3 (A3) since the weight of the F56 increases, the rank of A2 increases, and eventually, A2 becomes the most appropriate alternative. Similarly, when the weight of the subcriterion “F14-Annual flow” increases, A3 has become the most appropriate one. On the contrary, the rank of A4 is decreased. Therefore, it can be said that the annual flow of the A4 is lower than A3, which has a direct effect on their ranks when the local weight of the “F14-Annual flow” is increased.

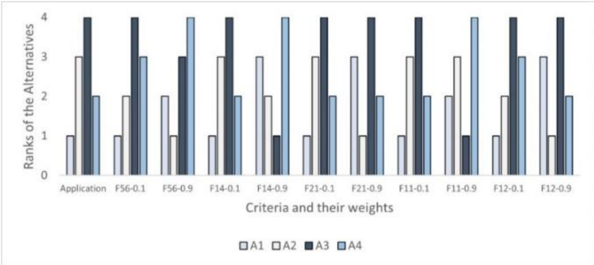

Fig. 7. Scenarios and alternative ranks based on the updated local weights

As in Figure 7, for the “F21-Technology” subcriterion, when its weight gradually increases from 0.1 to 0.9, A2 becomes the most appropriate alternative, which means A2 is the most useful location in terms of usage of technological equipment. As in the subcriterion “F11-Capacity”, the same alternative as in the application result, A3, is affected positively at most, which has the most capacity in terms of electricity generation.

5. CONCLUSIONS

The importance of clean energy sources is increasing day by day for a sustainable environment and a better quality of life in terms of environmental effects. Hydropower plants are preferable alternatives due to their sustainability, low production cost, high response capability to the fluctuations in demand, and environment-friendly design. However, the selection of the right plant location is essential to achieve these advantages. The plant location should also satisfy different criteria emerged by law and the expectations of multiple actors. In this study, the hydropower plant location alternatives have been compared, and the best one has been decided to depend on the most influential criteria on the success of the hydropower plants. An application is carried out to evaluate the location alternatives with respect to the critical criteria for the success by using an integrated decision-making methodology consisting of DEMATEL, cognitive mapping, and TOPSIS techniques based on hesitant fuzzy z-numbers. For the first stage of the methodology, a list of criteria for the success of a hydropower plant has been determined based on literature review and experts’ evaluation. In the second stage, an extended DEMATEL method based on hesitant fuzzy z-numbers has been designed to determine the dependencies between the criteria. Based on the outcomes of the extended DEMATEL method, the cognitive map structure has been constructed. As a result, the subcriteria “F56- Availability of Water”, “F14-Annual flow”, “F21-Technology”, “F11-Capacity”, and “F12-Annual energy production” have been determined as the most influential subcriteria among the other based on the constructed context. Finally, an extended TOPSIS method has been conducted for the prioritization of the hydropower energy plant locations. Moreover, based on the comparative and sensitivity analyses, it has been found that the proposed approach determines success factors in a practical, precise, and appropriate way in a broad assessment perspective.

The proposed methodology can be extended based on literature reviews, expert knowledge, and international quality standards as of future studies. Moreover, a multi-expert procedure can be applied to create a dataset with a wide range of evaluations.

REFERENCES

1. T. Supriyasilp, K. Pongput and T. Boonyasirikul, "Hydropower development priority using MCDM method," *Energy Policy,* vol. 37, no. 5, pp. 1866-1875, 2009.
2. L. A. Zadeh, "Fuzzy sets," *Information and Control,* vol. 3, no. 8, pp. 338-353, 1965.
3. V. Torra, "Hesitant fuzzy sets," *International Journal of Intelligent Systems,* pp. 529-539, 2010.
4. R. M. Rodríguez, L. Martínez and F. Herrera, "A group decision-making model dealing with comparative linguistic expressions based on hesitant fuzzy linguistic term sets," *Information Sciences,* vol. 243, pp. 28-42, 2013.
5. L. A. Zadeh, "A note on Z-numbers," *Information Sciences,* vol. 181, no. 14, pp. 2923-2932, 2011.
6. Z. Ren, H. Liao and Y. Liu, "Generalized Z-numbers with hesitant fuzzy linguistic information and its application to medicine selection for the patients with mild symptoms of the COVID-19," *Computers & Industrial Engineering,* vol. 145, p. 106517, 2020.
7. D. K. Iakovidis and E. Papageorgiou, "Intuitionistic fuzzy cognitive maps for medical decision making," *IEEE Transactions on Information Technology in Biomedicine,* vol. 15, no. 1, pp. 100-107, 2010.
14. B. O. Saracoglu, "Location selection factors of small hydropower plant investments powered by SAW, grey WPM and fuzzy DEMATEL based on human natural language perception," *International Journal of Renewable Energy Technology,* vol. 8, no. 1, pp. 1-23, 2017.
15. S. Abdullah and M. Aslam, "New multicriteria group decision support systems for small hydropower plant locations selection based on intuitionistic cubic fuzzy aggregation information," *International Journal of Intelligent Systems,* vol. 35, no. 6, pp. 983-1020, 2020.
16. B. A. Shimray, K. M. Singh, T. Khelchandra and R. K. Mehta, "A new MLP–GA–Fuzzy decision support system for hydro power plant site selection," *Arabian Journal for Science and Engineering,* vol. 43, no. 12, pp. 6823-6835, 2018.
17. F. Chien, C. N. Wang, V. T. Nguyen, V. T. Nguyen and K. Y. Chau, "An Evaluation Model of Quantitative and Qualitative Fuzzy Multi-Criteria Decision-Making Approach for Hydroelectric Plant Location Selection," *Energies,* vol. 13, no. 11, p. 2783, 2020.
18. D. Filev and R. R. Yager, "On the issue of obtaining OWA operator weights," *Fuzzy sets and systems,* vol. 94, no. 2, pp. 157-169, 1998.

19. A. Gabus and E. Fontela, "World problems, an invitation to further thought within the framework of DEMATEL," *Psychology,* 1972.
20. E. Fontela and A. Gabus, The dematel observer, Geneva: Geneva research center, 1976.
21. X.-F. Ding and H.-C. Liu, "A 2-dimension uncertain linguistic DEMATEL method for identifying critical success factors in emergency management," *Applied Soft Computing,* vol. 71, pp. 386-395, 2018.
22. E. C. Tolman, "Cognitive maps in rats and men," *Psychological review,* vol. 55, no. 4, p. 189, 1948.
23. B. Kosko, "Fuzzy cognitive maps," *International journal of man-machine studies,* vol. 24, no. 1, pp. 65-75, 1986.
24. A. M. Yaakob and A. Gegov, "Interactive TOPSIS based group decision making methodology using Z-numbers," *International Journal of Computational Intelligence Systems,* vol. 9, no. 2, pp. 311-324, 2016.
25. DSI, "Annual report for 2020", *Republic of Turkey Ministry of Agriculture and Forestry*, Ankara, 2021.
26. İ. Kaya, A. Karaşan, F. K. Gündoğdu and G. Işık, "Causal Investigation for Determining Critical Success Factors of Hydropower Plants by Considering Two-Dimensional Uncertain Linguistic Variables," 2021 International Conference on Green Energy, Computing and Sustainable Technology (GECOST), 2021.

İhsan Kaya (伊桑·卡亚) is currently Professor at Yildiz Technical University. His research interests are quality control and decision-making.

Gürkan Işık (古尔坎·伊西克) has a Ph.D. degree in Industrial Engineering. His research interests include fuzzy sets and soft computing.

Ali Karaşan (阿里卡拉桑) has a Ph.D. degree in Industrial Engineering. His research interests include fuzzy logic and decision-making.

Fatma Kutlu Gündoğdu (法特玛·贡多杜) is currently an Assist. Prof. at National Defence University. Her research interests include fuzzy logic,

Hayri Baraçlı (海里·巴拉克利) is currently Assist. Prof. at Yildiz Technical University. His research interests include fuzzy logic and decision-making.