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Strategic Analysis in the Selection of Sites for NPP Construction Based on Fuzzy Logic Methods

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The article presents an approach to the strategic analysis of the process of selecting nuclear power plant (NPP) construction sites based on fuzzy logic methods. The subject of the study is a comparative analysis of potential NPP construction sites. The object of the study is a methodology for systematic assessment of factors for analyzing NPP sites. The purpose of the study is to formalize the process of assessing the environment, its non-parametric factors, their classification by the degree of influence on the state of the research object and their impact on the decision-making process based on the use of fuzzy logic methods. The implementation of the method is based on expert assessments of groups of factors that determine the parameters of site evaluation. The method is based on the tools of fuzzy set theory: linguistic assessments of factors using triangular membership functions; Fuzzy Analytic Hierarchy Process (AHP) method for determining fuzzy importance coefficients of selected groups of factors of the proposed model; Center of Area (CoA) method for defuzzification of fuzzy triangular values; Fuzzy Simple Additive Weighting (SAW) method for ranking factors and selecting an effective strategic solution. For the strategic analysis of the state of NPP construction sites, a modified informative matrix for assessing the state of the system by J. Wilson was used. The following external system characteristics were selected for the study: a group of economic factors, a group of social factors, and a group of security factors. The group of experts conducted a fuzzy assessment of pairwise comparisons for the groups of factors and determined fuzzy estimates of the probabilities of the impact of external factors. The use of fuzzy linguistic estimates of the impact of external factors on the enterprise's activities and fuzzy values of the probability of their realization allows us to build an improved J. Wilson matrix. Each factor under consideration is positioned in this matrix according to linguistic estimates. This makes it possible to visually present the distribution of the identified factors by the importance of influence and the probability of realization of this influence. The developed model for generalized assessment of factors for each site allows decision makers to evaluate and compare sites taking into account the degree of implementation of the relevant groups of factors. The direction of further research is to include criteria in the model that detail the selected groups of factors and determine the integral assessments of sites based on them.

Introduction

From a systems approach perspective, the process of selecting a site for nuclear power plant (NPP) construction can be viewed as the implementation of a decision-making support system analyzing a diverse set of various factors and their criteria [1]. Deploying an NPP as a potential source of electricity production requires an in-depth feasibility analysis, which considers natural conditions, land use, public perception of the facility, and its environmental impact. Comprehensive consideration of these factor groups determines the cost of NPP construction, its long-term environmental footprint, public safety, and other operational aspects throughout its lifecycle.

Typically, among the multitude of factors influencing the selection process, alongside technical and technological factors, there are external ones, such as economic, social, demographic, historical etc. These factors can be represented non-parametrically, often by qualitative, linguistical means. Moreover, when the subject of decision-making is the selection of an NPP construction site, its external environment is characterized by significant complexity and inherent uncertainty [2]. This necessitates the objective formalization of external environmental factors, criteria, and indicators, along with their systematic assessment and classification.

The object of this study is the process of systematic analysis of potential NPP sites. The subject of the study is the comparative analysis of these potential sites based on comprehensive evaluation of relevant factors. The aim is to develop a methodology for strategic analysis and to formalize the NPP site selection process by assessing the external environment and its nonparametric factors, determining their influence on the research object and the decision-making process with the use of fuzzy logic methods.

Given the above, the development of scientifically grounded approaches to the comprehensive assessment of complex systems, exemplified by the analysis of NPP site selection, is highly relevant. This involves creating a model that evaluates not only the site itself but also the components underlying its overall assessment. Such evaluations will enable decision-makers to conduct a strategic analysis of potential sites.

To achieve the research objective, a methodological approach based on fuzzy sets theory is proposed. Fuzzy methods enable the modeling of real-world processes under conditions of incomplete and imprecise data, which are characteristic of this domain. The application of fuzzy models allows enhancing the accuracy of site assessments and incorporating varying selection strategies in decision-making. The proposed method integrates fuzzy logic techniques, ensuring a more precise consideration of uncertainty and expert assessments subjectivity in developing strategies for selecting NPP construction sites.

General approaches to formulating requirements for NPP site selection

The selection of a site for constructing an NPP as a potential technology for electricity generation requires a thorough analysis of its necessity and feasibility. The site selection process involves various considerations, including:

natural conditions;
land use;
public perception;
environmental impact, etc.

Taking these groups of factors into account has a profound impact on construction costs, environmental conditions, public safety, and other aspects throughout the entire lifecycle of the NPP.

Factors influencing decisions on nuclear power deployment vary between countries. Some of these factors are technical, such as site selection and the safety of nuclear technology deployment, with a clear connection to safety issues. Others are economic, including capital costs and investments, while yet others are social, with corresponding safety concerns, including environmental impact, proliferation risks, and waste management issues [3].

The fundamental safety objective is to protect people and the environment from the harmful effects of ionizing radiation [4], [5]. Considering that an NPP entails significant risks owing to the substantial quantities of nuclear fuel and high-level radioactive waste, the IAEA has developed specific standards and guidelines for site selection.

Site selection constraints are considered strictly mandatory, but the methodology for site selection depends entirely on the operating organization and local regulatory authority. However, in general, site selection should strike a balance between various factors, such as economic interests, public relations, and safety [6], considering public health and safety, economic aspects, institutional requirements, environmental impact, and other factors [7].

Thus, to date, no definitive standard exists for the methodology of NPP site selection. However, the general approach involves ensuring safety and protecting the public from harmful radiation exposure, while minimizing such impacts during the selection process. Implementing NPP siting safety principles should rely on detailing the factors to be considered during site selection. The process of forming a set of factors is entrusted to national regulatory bodies and is developed based on the unique characteristics of each country. Additionally, the sets of criteria included in the selected groups of factors can also differ in content.

In [8], recommendations from the IAEA and the approaches of national regulators in 17 countries of Southeast Asia and the Middle East were analyzed to define factors and criteria for solving the problem of selecting

NPP construction sites. For comparative analysis, classes of factors and their criteria are examined from social, economic, and technical perspectives. The procedure for analyzing criteria to select an NPP site can be represented as a sequential process of forming data sets, their generalizing, comparison, and decision-making. The hierarchical tree of the NPP site selection process is shown in Fig. 1.

From the perspective of systems analysis, the site selection procedure is a complex process involving the simultaneous consideration of diverse factors and their criteria. This requires, first, their formalization and, second, the use of appropriate mathematical tools to determine generalized assessments of both factor groups for various objects and the overall (integral) assessment of each individual object. In this regard, it appears appropriate to apply fuzzy logic tools for strategic analysis in the process of selecting NPP sites.

Analysis of research on using fuzzy logic methods in strategic analysis of complex systems

According to the definition by the classical strategic analysis theorist H. Igor Ansoff [9], [10], "strategic analysis of the external environment is a comprehensive study of an organization's external environment (industry, competitors, customers, suppliers) to evaluate opportunities and threats and to develop an optimal economic strategy based on the selection among possible alternatives".

Strategic analysis primarily relies on classical tools for comprehensive evaluation of external environmental factors (ETOM, EFEM, PESTEL, SWOT analysis, etc.) [11], [12], [13]. The study [14] evaluates and compares these tools, exploring their applicability to the strategic analysis of various enterprises and large-scale production systems.

Given that the subject of this research is NPP construction sites — as complex structural systems involving arrays of both parametric (quantitative) and non-parametric (qualitative, linguistic) indicators — the application of fuzzy logic theory presents a promising approach to addressing problems in their strategic analysis [15], [16].

In the study [17], a fuzzy approach was proposed for evaluating the influence of external factors on an enterprise strategy. A methodological framework was developed for evaluating and selecting strategic alternatives for the enterprise using fuzzy multi-criteria analysis and fuzzy logic tools. This approach enables the enterprise top management to rank the value of the developed strategic alternatives, thereby expanding the effectiveness of classical methods for strategic decision-making.

In [18], the Fuzzy DEMATEL method was applied to risk analysis in the construction industry, demonstrating its potential for identifying critical external environmental factors. Similarly, in [19] the authors proposed fuzzy logic methods to address key challenges in traditional strategic planning, such as considering internal and external factors in uncertain and imprecise environments. This model was successfully applied within an information technology corporation, showcasing its effectiveness in real-world scenarios.

Given the reliance of strategic analysis on expert assessments of external factors — often expressed linguistically or qualitatively — there is a clear need to enhance current tools for better incorporation of subjective, non-formalized, imprecise input data and expert judgments. As such, one promising research direction involves developing a decision-making support system for strategic analysis of factors in selecting NPP construction sites, leveraging fuzzy logic methods.

Research methodology

To conduct strategic analysis, this study proposes a method based on fuzzy sets theory. Unlike the existing approaches, this method considers model factors according to linguistic expert evaluations obtained through the sequential application of fuzzy logic methods, including Fuzzy AHP (Fuzzy Analytic Hierarchy Process), CoA (Centre of Area), Fuzzy SAW (Fuzzy Simple Additive Weighting), and a system state assessment modified informative Wilson matrix. This approach enables a more comprehensive consideration of subjective, non-formalized, and imprecise input data, as well as expert opinions and judgments. In this methodology Fuzzy AHP is used to determine factors fuzzy importance coefficients [20]; CoA method is applied for defuzzification of fuzzy triangular values [21]; Fuzzy SAW method facilitates the ranking of risk factors and selection of an effective strategic decision [22]; the modified Wilson matrix is employed to visualize the obtained results.

Strategic analysis of the external environment for NPP site selection is proposed to be conducted according to the following:

Stage 1: Identification of external environmental factors

External factors influencing NPP site selection include economic factor with its criteria (EC), social factor with its criteria (ScC), and safety factor with its criteria (SfC) (see Fig. 1).

Stage 2: Calculation of fuzzy values of factors importance

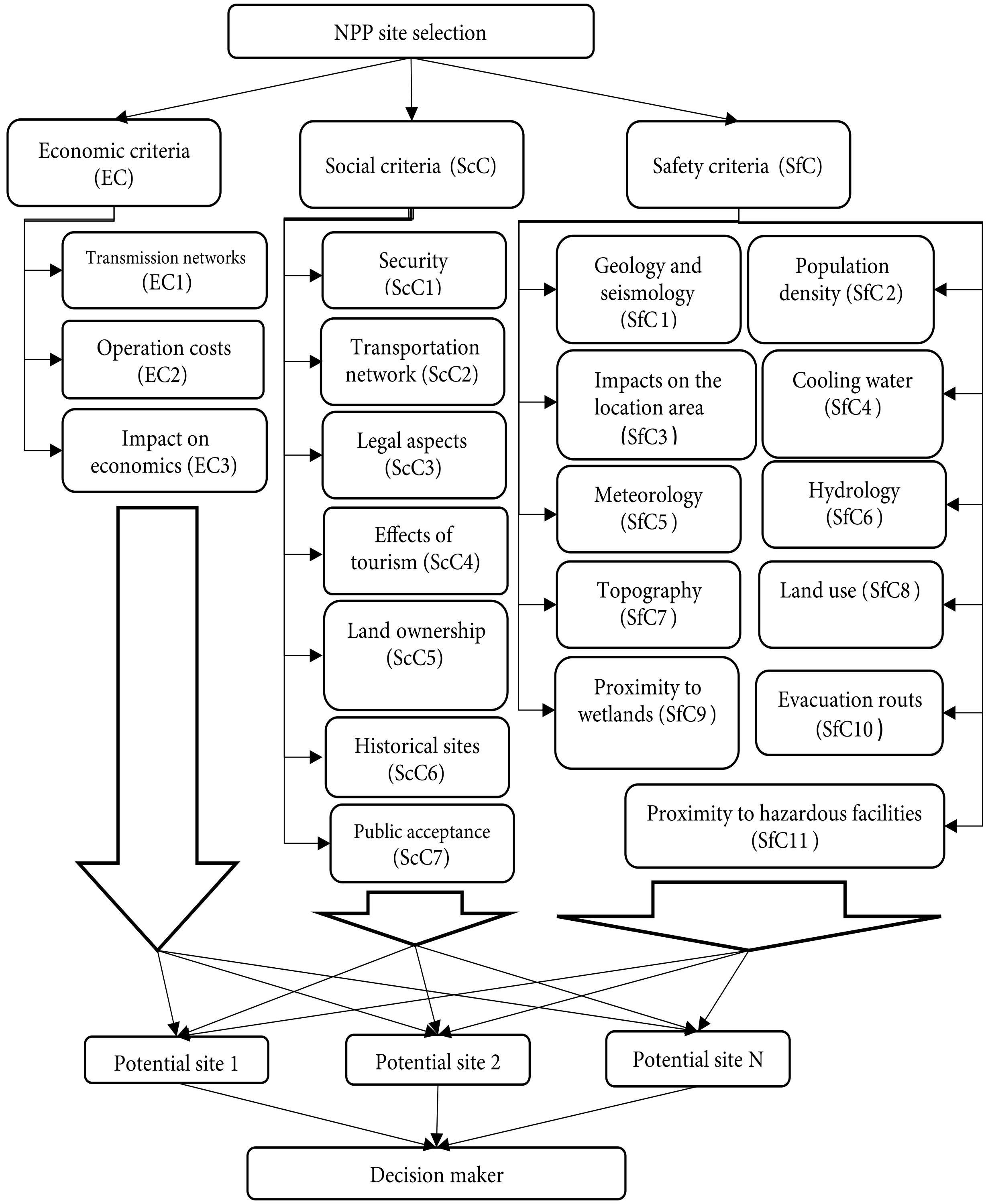

Fig. 1. Hierarchical tree for analysis and selection of sites for NPP construction

The Fuzzy AHP method is used to calculate the fuzzy values of the importance of factors influencing the assessment of potential sites:

Step 2.1. Expert evaluation of pairwise comparisons of factors (or criteria within each factor for in-depth analysis) based on a linguistic scale (term set T1), Table 1.

Step 2.2. Construction of fuzzy pairwise comparison square matrices of the factors or criteria based on evaluations from Step 2.1., Stage 2*:*

Table 1. Scale for conversion of linguistic terms to fuzzy triangular numbers

Linguistic terms T1 for determining the relative importance of factors (i-th factor compared to j-th factor)	Notation	Numerical value of pairwise comparison of factors/criteria	
		$a_{ij}(\alpha_{ij}, \beta_{ij}, \gamma_{ij})$	$a_{ji} = \frac{1}{a_{ij}}$
Equal	E	(1; 1; 1)	(1; 1; 1)
Moderate	M	(2; 3; 4)	(1/4; 1/3; 1/2)
Strong	S	(4; 5; 6)	(1/6; 1/5; 1/4)
Very Strong	VS	(6; 7; 8)	(1/8; 1/7; 1/6)
Extremaly Strong	ES	(8; 9; 9)	(1/9; 1/9; 1/8)

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \\ = \begin{bmatrix} (1,1,1) & (\alpha_{12}, \beta_{12}, \gamma_{12}) & \dots & (\alpha_{1n}, \beta_{1n}, \gamma_{1n}) \\ (\alpha_{21}, \beta_{21}, \gamma_{21}) & (1,1,1) & \dots & (\alpha_{2n}, \beta_{2n}, \gamma_{2n}) \\ \dots & \dots & \dots & \dots \\ (\alpha_{n1}, \beta_{n1}, \gamma_{n1}) & (\alpha_{n2}, \beta_{n2}, \gamma_{n2}) & \dots & (1,1,1) \end{bmatrix}, \quad (1)$$

where $\tilde{a}_{ij} = (\alpha_{ij}, \beta_{ij}, \gamma_{ij})$, $\tilde{a}_{ji} = \tilde{a}_{ij}{}^{-1} = (\frac{1}{\gamma_{ij}}, \frac{1}{\beta_{ij}}, \frac{1}{\alpha_{ij}})$,

$$i, j = 1, \dots, n, \quad i \neq j.$$

Step 2.3. Aggregation of fuzzy pairwise comparison matrices to calculate an integrated fuzzy pairwise comparison matrix of the determined factors by transforming linguistic evaluations of K-experts into fuzzy numbers based on the scale (Table 1):

$$\begin{cases} \tilde{A} \to \widetilde{F_k} = \left\|\widetilde{f_k}\right\|_{n\times n} \\ \widetilde{F_k} = \frac{1}{K} \oplus_{k=1}^{K} \widetilde{f_k} = \\ = \left(\frac{1}{K}\sum_{k=1}^{K} \alpha_{k_{ij}}, \frac{1}{K}\sum_{k=1}^{K} \beta_{k_{ij}}, \frac{1}{K}\sum_{k=1}^{K} \gamma_{k_{ij}},\right) = \\ = \left\|\left(\alpha_{k_{ij}}, \beta_{k_{ij}}, \gamma_{k_{ij}}\right)\right\|_{n\times n,} \end{cases} \quad (2)$$

where k=1,2,...,K – number of experts.

Step 2.4. Calculation of fuzzy geometric mean values for matrix components Fk:

$$\tilde{S}_i = \left(\sqrt[n]{\alpha_{i1} \times \dots \times \alpha_{in}}; \sqrt[n]{\beta_{i1} \times \dots \times \beta_{in}}; \\ \sqrt[n]{\gamma_{i1} \times \dots \times \gamma_{in}}\right) = (\alpha_i, \beta_i, \gamma_i), \quad (3)$$

fuzzy vector sum of geometric mean values:

$$\tilde{r} = \tilde{S}_1 \oplus \dots \oplus + \tilde{S}_n = \begin{Bmatrix} \alpha_i + \dots \times \alpha_n \\ \beta_i + \dots + \beta_n \\ \gamma_i + \dots + \gamma_n \end{Bmatrix} = (r_\alpha, r_\beta, r_\gamma) \quad (4)$$

and their inverse values

$$(\tilde{r})^{-1} = \left(\frac{1}{r_\alpha}, \frac{1}{r_\beta}, \frac{1}{r_\gamma}\right). \quad (5)$$

Step 2.5. Evaluation of fuzzy importance indexes of the determined factors v_i and their relative weights w_i:

$$\begin{cases} \tilde{v}_i = (\alpha_i, \beta_i, \gamma_i) \otimes \left(\frac{1}{r_\alpha}; \frac{1}{r_\beta}; \frac{1}{r_\gamma}\right) = (v_{1i}; v_{2i}; v_{3i}) \\ \widetilde{w}_i = \left(\frac{v_{1i}}{\sum_{i=1}^{n}\left(\widetilde{v_i}\right)^{def}}; \frac{v_{2i}}{\sum_{i=1}^{n}\left(\widetilde{v_i}\right)^{def}}; \frac{v_{3i}}{\sum_{i=1}^{n}\left(\widetilde{v_i}\right)^{def}}\right) = \\ = (w_{1i}; w_{2i}; w_{3i}). \end{cases} \quad (6)$$

Stage 3: Estimation of NPP site selection external environmental factors influence probability fuzzy values. The external factors influence occurrence probability is linguistically evaluated using the term set T2 = {very low — VL; low — L; medium — M; high — H; very high — VH}. The semantics of these terms are represented as fuzzy numbers in the range [0; 1] (Table 2).

For each k-th expert, fuzzy estimates of external factors occurrence probability are determined p=$p1$,...,pK by sequentially implementing Steps 1 to 3 of the algorithm for the whole array of factors and criteria.

Stage 4: Estimation of external factors influence level fuzzy values. NPP site selection external factors and the levels of their influence on decision-making strategy are assessed as linguistic variables (term set T3). The semantics of these terms are represented as fuzzy numbers in the range [-6; 6], with corresponding membership functions and triangular fuzzy representations (Table 3).

As a result, for each k-th expert, fuzzy estimates of external factors influence levels are determined $\widetilde{inf} = (\widetilde{inf}_1, \dots, \widetilde{inf}_K)$.

Using fuzzy linguistic evaluations of external factors influence on NPP site selection along with their occurrence probability fuzzy values, an enhanced and detailed Wilson matrix is constructed to assess the positive and

Table 2. Evaluation of factors influence occurrence probabilities

Linguistic terms T2 for estimation of fuzzy probability values of NPP site selection external environmental factors influence occurrence	Notation	Semantics of terms pi
Very low	VL	(0.0; 0.0; 0.25)
Low	L	(0.15; 0.3; 0.45)
Medium	M	(0.35; 0.5; 0.65)
High	H	(0.55; 0.7; 0.85)
Very high	VH	(0.75; 1; 1)

Table 3. Evaluation of factors influence level

Linguistic terms T3 for estimation of fuzzy influence values of NPP site selection external factors influence level	Notation	Ter (t/o*)	
		Negative influence, “threats” (t)	Positive influence, “opportunities” (o)
No Significant	NS	(−1; 0; 0)	(0; 0; 1)
Very low	VL	(−2;-1; 0)	(0; 1; 2)
Low	L	(−3; – 2; −1)	(1; 2; 3)
Medium	M	(−4; – 3; – 2)	(2; 3; 4)
High	H	(−5; – 4; – 3)	(3; 4; 5)
Very high	VH	(−6; – 5; – 4)	(4; 5; 6)
Extremely High	EH	(−6; – 6; – 5)	(5; 6; 6)

*With the index «t» – Threats or «o» – Opportunity

negative impacts of factors (opportunities and threats), as shown in Fig. 2.

Each evaluated factor is positioned within this matrix based on the linguistic evaluations obtained on the Stages 3 and 4, enabling a visual representation of the distribution of these factors by their influence level and its occurrence probability.

Testing the algorithm for strategic analysis of NPP construction sites

To validate the proposed methodology, a strategic analysis of sites for NPP construction was conducted using the example of the EC (Stage 1).

$$EC = \begin{cases} EC_1 - \text{«Energy transmission networks»} \\ EC_2 - \text{«Operation costs»} \\ EC_3 - \text{«Impacts on the economy»} \end{cases}$$

As in [2], the evaluation involved 12 qualified experts who performed pairwise comparisons of factors for three potential sites: Khmelnytskyi NPP, Rivne NPP, and South Ukraine NPP, based on a linguistic scale (term set T1) (Stage 2, Step 2.1). The expert linguistic evaluation of experts’ confidence level was defined as high (H). As a result, a total of 12 × 3 = 36 matrices were obtained, with their structure illustrated in Fig. 3.

To automate the calculation processes described in the proposed methodology (Stage 2, Steps 2.2–2.5, and Stages 3–4) and to facilitate the scientific analysis of strategic decisions, a specialized software module named “STRATEHIYA” was developed. The choice of cross-platform programming language Python ensured flexibility and scalability of the development while also opening up wide opportunities for seamless integration with other analytical tools and its further enhancement.

The architecture of the module is based on the efficient utilization of the following libraries:

NumPy: a package for scientific computing featuring the option of working with multidimensional arrays. It achieves performance levels comparable to specialized software packages for scientific calculations [23].

SciPy: a package for scientific and engineering computing that operates on NumPy arrays. It efficiently handles large datasets, allowing for in-depth analysis and identification of patterns [24].

Scikit-fuzzy (Skfuzzy): a package for fuzzy logic operations in Python, built to work with NumPy arrays. It provides access to a wide range of mathematical algorithms

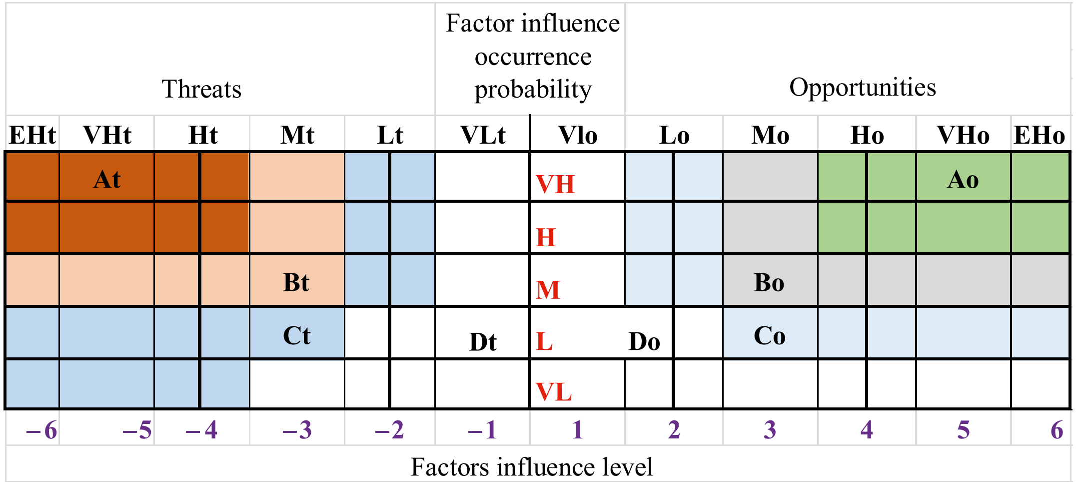

Fig. 2. Matrix of fuzzy evaluation of opportunities and threats of factors influence on the assessment of NPP site selection

Khmelnytskyi NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(2; 3; 4)	(4; 5; 6)	EC_1	(1; 1; 1)	(2; 3; 4)	(4; 5; 6)
EC_2	(0.25; 0.33; 0.5)	(1; 1; 1)	(2; 3; 4)	EC_2	(0.25; 0.33; 0.5)	(1; 1; 1)	(4; 5; 6)
EC_3	(0.17; 0.2; 0.25)	(0.25; 0.33; 0.5)	(1; 1; 1)	EC_3	(0.17; 0.2; 0.25)	(0.17; 0.2; 0.25)	(1; 1; 1)
Rivne NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(2; 3; 4)	(4; 5; 6)	EC_1	(1; 1; 1)	(2; 3; 4)	(1; 1; 1)
EC_2	(0.25; 0.33; 0.5)	(1; 1; 1)	(2; 3; 4)	EC_2	(0.25; 0.33; 0.5)	(1; 1; 1)	(2; 3; 4)
EC_3	(0.17; 0.2; 0.25)	(0.25; 0.33; 0.5)	(1; 1; 1)	EC_3	(1; 1; 1)	(0.25; 0.33; 0.5)	(1; 1; 1)
South Ukraine NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(4; 5; 6)	(2; 3; 4)	EC_1	(1; 1; 1)	(1; 1; 1)	(2; 3; 4)
EC_2	(0.17; 0.2; 0.25)	(1; 1; 1)	(4; 5; 6)	EC_2	(1; 1; 1)	(1; 1; 1)	(2; 3; 4)
EC_3	(0.25; 0.33; 0.5)	(0.17; 0.2; 0.25)	(1; 1; 1)	EC_3	(0.25; 0.33; 0.5)	(0.25; 0.33; 0.5)	(1; 1; 1)

Fig. 3. Fragment of results from fuzzy expert pairwise comparison of EC

and is designed to handle fuzzy concepts and uncertainty, which are characteristic of strategic decision-making processes [Scikit-fuzzy // API Reference [25].

Matplotlib: a comprehensive library for creating static, animated, and interactive visualizations in Python. It allows for clear and informative graphical representations, facilitating the interpretation of analytical results [26].

The sequential implementation of Steps 2.2–2.5 of Stage 2 enabled the calculation of fuzzy importance coefficients vi of the identified factors and their relative weights wi. The results are presented in Table 4.

At Stage 3 of the proposed algorithm, the fuzzy probabilities of the influence of economic factor criteria on the process of selecting a site for NPP construction were determined. The structure of the fuzzy matrices used for the probability determination is shown in Fig. 4, and the results of the probability calculations are presented in Table 5.

At the final stage of the algorithm (Stage 4), an evaluation of the influence levels of the economic factor components on the decision-making strategy for selecting an NPP construction site was conducted based on fuzzy expert evaluations (in accordance with the linguistic terms T3, Table 3). The results of aggregating the fuzzy assessments into crisp influence parameters are presented in Table 6.

The obtained results allow for the assessment of the influence level of EC and their classification within the "Threats — Opportunity" coordinates.

At the final stage of the algorithm, a modified Wilson matrix was constructed, integrating all intermediate

Table 4. Fuzzy importance indexes and relative weights of EC

Economic factor criteria	Importance index of the criterium v_i	Relative weight of the criterium w_i
Khmelnytskyi NPP		
EC_1 "Energy Transmission Networks"	0.244	0.370
EC_2 "Operation Costs"	0.210	0.319
EC_3 "Impacts on the Economy"	0.164	0.250
Rivne NPP		
EC_1 "Energy Transmission Networks"	0.244	0.370
EC_2 "Operation Costs"	0.204	0.309
EC_3 "Impacts on the Economy"	0.170	0.257
South Ukraine NPP		
EC_1 "Energy Transmission Networks"	0.243	0.367
EC_2 "Operation Costs"	0.201	0.302
EC_3 "Impacts on the Economy"	0.175	0.264

Khmelnytskyi NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(0.35; 0.5; 0.65)	(0.35; 0.5; 0.65)	EC_1	(1; 1; 1)	(0.35; 0.5; 0.65)	(0.15; 0.3; 0.45)
EC_2	(1.54; 2; 2.86)	(1; 1; 1)	(0.55; 0.7; 0.85)	EC_2	(1.54; 2; 2.86)	(1; 1; 1)	(0.75; 1; 1)
EC_3	(1.54; 2; 2.86)	(1.18; 1.43; 1.82)	(1; 1; 1)	EC_3	(2.22; 3.33; 6.67)	(1; 1; 1.33)	(1; 1; 1)
Rivne NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(0.55; 0.7; 0.85)	(0.35; 0.5; 0.65)	EC_1	(1; 1; 1)	(0.15; 0.3; 0.45)	(0.15; 0.3; 0.45)
EC_2	(1.18; 1.43; 1.82)	(1; 1; 1)	(0.75; 1; 1)	EC_2	(2.22; 3.33; 6.67)	(1; 1; 1)	(0.35; 0.5; 0.65)
EC_3	(1.54; 2; 2.86)	(1; 1; 1.33)	(1; 1; 1)	EC_3	(2.22; 3.33; 6.67)	(1.54; 2; 2.86)	(1; 1; 1)
South Ukraine NPP							
Expert 1				Expert 2			
	EC_1	EC_2	EC_3		EC_1	EC_2	EC_3
EC_1	(1; 1; 1)	(0.15; 0.3; 0.45)	(0.55; 0.7; 0.85)	EC_1	(1; 1; 1)	(0.15; 0.3; 0.45)	(0.15; 0.3; 0.45)
EC_2	(2.22; 3.33; 6.67)	(1; 1; 1)	(0.55; 0.7; 0.85)	EC_2	(2.22; 3.33; 6.67)	(1; 1; 1)	(0.35; 0.5; 0.65)
EC_3	(1.18; 1.43; 1.82)	(1.18; 1.43; 1.82)	(1; 1; 1)	EC_3	(2.22; 3.33; 6.67)	(1.54; 2; 2.86)	(1; 1; 1)

Fig. 4. Fragment of the results of fuzzy expert pairwise comparison of EC for their occurrence probabilities determination

Table 5. NPP site selection EC influence occurrence probability

Economic factor criteria, EC	Influence occurrence probability of the criterium, p_i
Khmelnytskyi NPP	
EC_1 “Energy Transmission Networks”	0.2902
EC_2 “Operation Costs”	0.3340
EC_3 “Impacts on the Economy”	0.3570
Rivne NPP	
EC_1 “Energy Transmission Networks”	0.2844
EC_2 “Operation Costs”	0.3345
EC_3 “Impacts on the Economy”	0.3684
South Ukraine NPP	
EC_1 “Energy Transmission Networks”	0.2828
EC_2 “Operation Costs”	0.3388
EC_3 “Impacts on the Economy”	0.3535

Table 6. Numerical estimates of the NPP site selection process EC influence levels

Economic factor criteria, EC	Influence level of the criterium, inf_i
Khmelnytskyi NPP	
EC_1 “Energy Transmission Networks”	2.92
EC_2 “Operation Costs”	4.47
EC_3 “Impacts on the Economy”	4.29
Rivne NPP	
EC_1 “Energy Transmission Networks”	3.92
EC_2 “Operation Costs”	3.63
EC_3 “Impacts on the Economy”	3.31
South Ukraine NPP	
EC_1 “Energy Transmission Networks”	–3.94
EC_2 “Operation Costs”	–5.32
EC_3 “Impacts on the Economy”	2.62

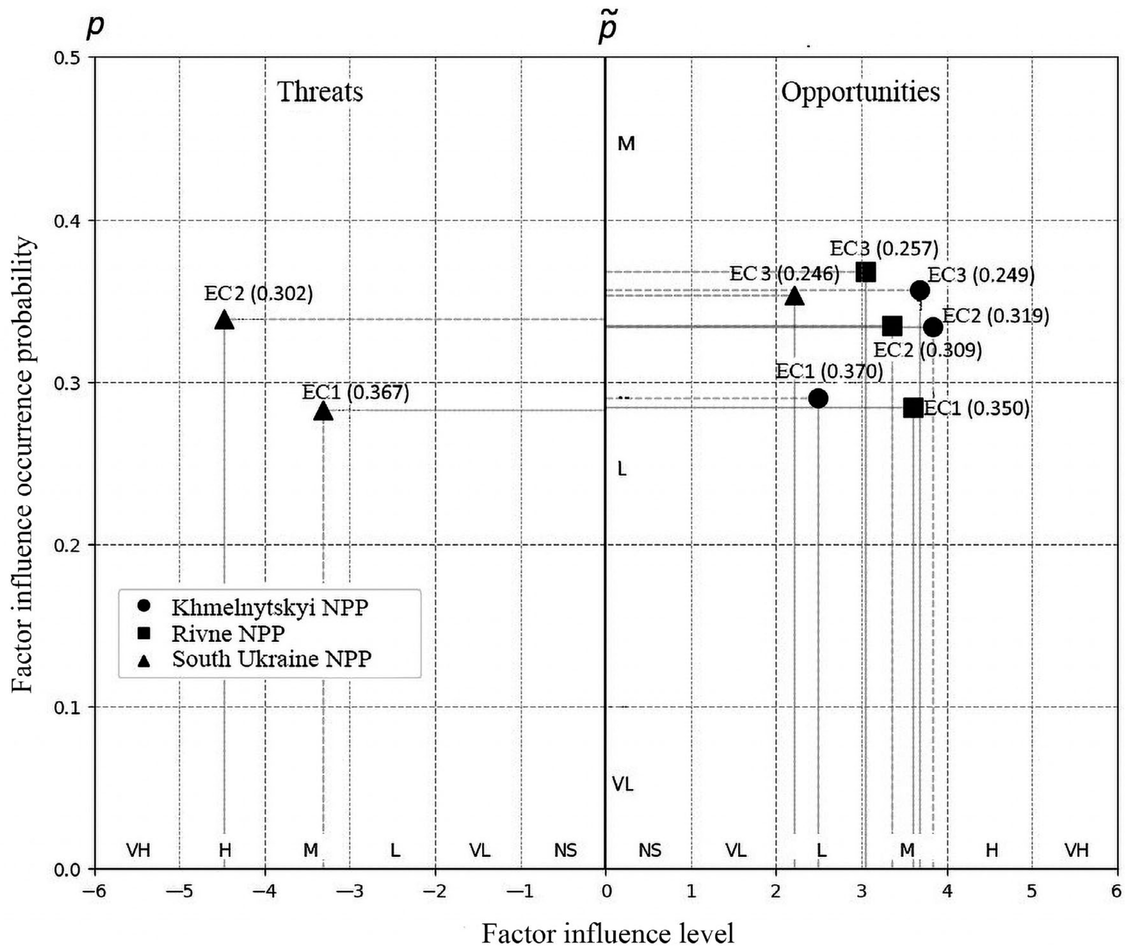

Fig. 5. Modified Wilson matrix for EC in NPP site evaluation

results. This matrix can serve as a visualization tool for decision-makers to facilitate corresponding managerial decisions (Fig. 5). In Fig. 5, the weights w_i of the respective $EC - EC_i(w_i)$ for different potential sites are presented. Additionally, upon the DM's request, the importance coefficients v_i of the criteria can also be provided.

Conclusions

This study presents a methodological approach to strategic analysis and an algorithm for evaluating factors and their criteria in the process of selecting the optimal site for NPP construction based on fuzzy logic methods. The implementation of the method relies on classical expert evaluation techniques for groups of factors, utilizing the tools of fuzzy set theory to assess potential sites. For the strategic analysis of NPP construction sites, a modified informative system state evaluation Wilson matrix was employed. Its application enables a more flexible approach to analyzing and incorporating expert-relevant information, subjective, non-formalized, fuzzy input data, and expert opinions and judgments. The application of the proposed methodological approach has provided substantiated conclusions regarding the impact of economic factor criteria on the preparation and adoption of strategic decisions. The developed model for generalized factor evaluation for each site allows decision-makers to assess and compare sites, considering the degree of realization of respective groups of factors.

The results of the pilot application of the proposed methodology reveal prospects for further research and testing of the developed method. This includes the comprehensive consideration of various factors and their criteria, the determination of integral site evaluations based on them, and the integration of the developed model into decision support systems for analyzing potential NPP construction sites.

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Стратегічний аналіз при виборі майданчиків для будівництва АЕС на основі методів нечіткої логіки

Представлено опис методичного підходу до оптимального вибору майданчиків для будівництва АЕС на основі застосування математичного апарату теорії нечітких множин. Реалізація підходу базується на експертних оцінках груп факторів, що визначають параметри оцінки майданчиків. Запропоновано проведення комплексного аналізу, побудованого на лінгвістичних оцінках факторів за допомогою трикутних функцій належності, методів Fuzzy Analytic Hierarchy Process (AHP), Centre of Area (CoA), Fuzzy Simple Additive Weighting (SAW). Для стратегічного аналізу стану майданчиків будівництва АЕС з метою вибору оптимального місця їх розміщення використана модифікована інформативна матриця оцінювання стану системи Дж. Вілсона. Розроблена модель для узагальненої оцінки факторів для кожного майданчика дає змогу особам, які приймають рішення, проводити оцінку та порівняння майданчиків з урахуванням ступеня реалізації відповідних груп факторів. Напрямом подальших досліджень є включення в модель критеріїв, які деталізують обрані групи факторів та визначення інтегральних оцінок майданчиків на їхній основі.

Ключові слова: стратегічний аналіз, вибір майданчика АЕС, експертні оцінки, лінгвістичні змінні, методи нечіткої логіки, факторний аналіз та оцінка, матриця Вілсона, підтримка прийняття рішень.

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