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MULTI-CRITERIA INVESTMENT DECISION SUPPORT MODEL USING FUZZY ANALYTIC HIERARCHY PROCESS (F-AHP) METHOD FOR POWER INDUSTRY

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Summary: In this paper, the comparative analysis of two wind farm construction projects was presented. This particular type of analysis is commonly applied before purchasing investment project being in a planning phase by a company interested in its development. Conduction of this type of analysis is prompted by the necessity to take into consideration the requirements of Polish legislation. Comparison of wind farm construction projects was based on the analysis of their advancement and the priority of particular investment stages. In order to verify which stage is the most important for the implementation of the construction project, specified tasks should be performed in each particular stage. These tasks determine criteria utilized to compare wind farm construction projects. Fuzzy Analytic Hierarchy Process (F-AHP) method, that allows simultaneous prioritization of criteria in terms of quality and quantity, was applied to perform the analysis. The method demonstrates that obtaining environmental decision for wind farm area is the most important criterion. The method indicate also by which criteria project FW2 has a greater chance of implementation than FW1 project.

Keywords: Fuzzy Analytic Hierarchy Process, wind farm, investment process

1. INTRODUCTION

Increasing interest in the construction of wind farms is related to the requirements imposed by the implementation of Energy Policy of the European Union. One of its goals is to increase the share of renewable energy sources (RES) in electricity production within EU to at least 20%by 2020. Poland, as an EU Member State, adopted the policy in its legal framework and energy policy. To meet the goal, renewable energy projects, including wind farms, must be implemented. Wind conditions in Poland are favorable, which attracts both domestic and foreign investors. Requirements of aerodynamic terrain roughness around the planned wind farm make investors decide to build them in rural areas. According to [1], wind projects contribute to financial benefits for rural municipalities. They are expected to encounter widespread commercial success, because their electricity production is free from any physical pollution [2].

Growing interest in wind farm investments necessitate the profitability analysis of each project. This is due to the fact that there is number of events that can threaten the success of the implementation of each project stage. Protests of the local community, which can significantly extend the duration of the project, may force investors to abandon it. Therefore, it is crucial to select, at each project stage, priority tasks to maximize the probability of wind farm project accomplishment.

2. LITERATURE REVIEW

There are available studies concluded application of Fuzzy Analytic Hierarchy Process (F-AHP) for power industry. For example Kahraman used F-AHP method to select the most appropriate renewable energy alternative [3], Ma and Chang proposed a technology selection process integrating F-AHP and Delphi method for Taiwan's future photovoltaic industry [4], Chen et al. used F-AHP method to select suitable projects for hybrid solar-wind power generating system [5]. After short summarizing the aforementioned literature, this study proposed using F-AHP method to compare two wind farms construction projects.

3. RESEARCH METHOD

The investment process of building wind farm consists of a series of tasks to be completed in order to get all necessary studies and decisions to obtain planning permission. These tasks were placed in a hierarchical structure in the form of criteria affecting the implementation of the overall goal. Criteria were placed below the overall goal, being on the top of the hierarchical structure, and variants were placed on the bottom structure level (as in fig. 1). Creating the structure of the problem as a hierarchy was first proposed by T. L. Saaty [6] and named Analytic Hierarchy Process (AHP). The Fuzzy Analytic Hierarchy Process (F-AHP) method, applied in this study, uses the knowledge of experts to determine the hierarchical structure describing the matter and the weight coefficients describing the relationship between elements in the structure. As a result, it is possible to eliminate criteria, which do not affect the overall goal. Compared with non-fuzzy AHP, application of F-AHP with fuzzy expert opinion allows to make a more realistic assessment than application of AHP using non-fuzzy opinion [7]. The first step of the analysis is to identify the overall goal of the analysis and to select criteria affecting its reaching. The next step is pair-wise comparison of criteria by giving one criterion a preference over another. In the AHP method [6], preferences of criterion are determined by a nine-point scale pair-wise comparison. In the F-AHP method, nine-point scale was replaced by triangular fuzzy numbers of linguistic comparison measures (Tab. 1). After pair-wise comparison the weight vector is given. By normalization this vector the normalized weight vector with non-fuzzy numbers is created [8]. Detailed presentation of F-AHP method was included in [9][10].

4. IMPLEMENTATION

For the financial viability of the investment, the time needed to obtain planning permission for wind farm construction should be as short as possible. This is the overall goal adopted in this F-AHP study. Wind farm construction projects are variants. In order to compare decision variants, in terms of their impact on the overall goal, the main pair-wise comparisons should be made with regard to particular criterion. The purpose of the comparison is to identify which of the projects has a better chance of getting all the necessary decisions and permits to obtain planning permission in shorter time. Criterion no. 1 is related to the measurement of wind kinetic energy for a wind farm project. This energy is measured by devices mounted on a measurement mast. It is recommended to conduct measurements for at least five years, if reliable data is needed. Significant difference between the heights of measurement mast and wind turbine mast may result in incorrect evaluation of electricity production.

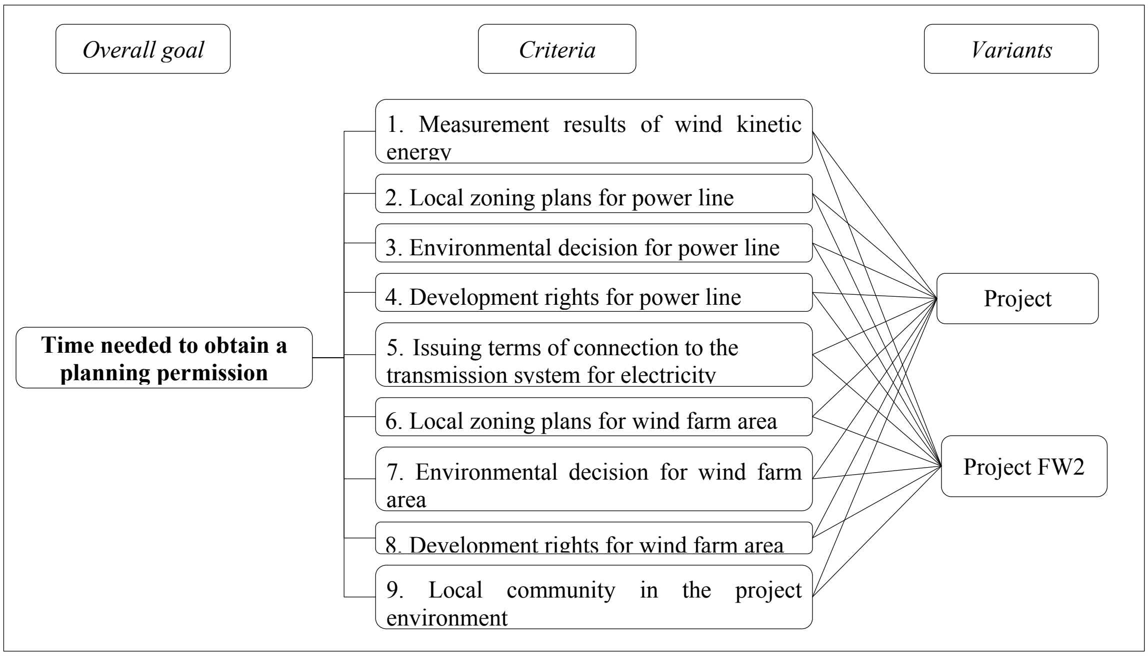

Fig. 1. Hierarchical structure of selecting projects in terms of time needed to obtain planning permission

Tab. 1. Triangular fuzzy numbers of linguistic comparison measures, own study based on Saaty[6] and Łuczak[7]

Definition	Intensity of importance on an absolute scale		Explanation
	AHP	F-AHP	
Equal importance	1	(1,1,1)	Two activities contribute equally to the objective
Moderate advantage of one over another	3	(1,3,5)	Experience and judgment favor one activity over another
Essential advantage	5	(3,5,7)	Experience and judgment strongly favor one activity over another
Significant advantage	7	(5,7,9)	An activity is strongly favored and its dominance is demonstrated in practice
Extreme advantage	9	(7,9,9)	The evidence favoring one activity over another is of the highest possible order of affirmation
Intermediate values between the two adjacent judgments	2,4,6,8	(1,2,4);(2,4,6); (4,6,8); (6,8,9)	When compromise is needed
Reciprocals	Invert of assessments		If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

Criteria no. 2 and no. 6 concern including, in local zoning plans, both wind farm area and power line area. If they are not included, the plans should be changed. Enacting local zoning plans is a time consuming process and can significantly affect the investment accomplishment. This is due to, *inter alia*, a number of documents and studies required to change local zoning plan. One of them is to obtain environmental decision for wind farm (criterion no. 7) and power line construction (criterion no. 3). It is a complex process, because of the amount of environmental monitoring and the number of environmental reports that must be performed. For environmental report needs, the investor is obliged to conduct environmental monitoring in specific time periods of the year, e.g. during bird migration. As a result, wind farm cannot obtain environmental decision or planning permission within a certain period of the year, which delays the process and reduces the profitability of investment. Additionally, in the process of obtaining the environmental decision, local community participation is possible. It is therefore necessary to conduct information and promotion campaign to reduce the risk of local community protests against the project (criterion no. 9)[11]. In the planning phase of a wind farm construction, the investor secures development rights so that after obtaining all the necessary permits they can start the construction of a wind farm along with the associated infrastructure.

The electricity produced is supplied to the grid by power line. A very important issue is to conclude an agreement with transmission/distribution system operator to connect the wind farm to the network so that the electricity produced can reach the consumer. The first step to conclude an agreement is to achieve the issuing of terms of connection to the transmission/distribution grid (criterion no. 5). In order to get these terms, the investor must both prove that wind farm location is included in local zoning plans and submit development rights with the aim to build a particular wind farm. If the transmission/distribution grid enables to connect wind farm to the grid and no other entity is applying for issuing terms of connection to the transmission grid in the nearest connection point, there is a high probability that the agreement will be concluded.

Projects compared in this paper are currently in the pipeline. Installed capacities of wind farms are comparable. Wind farm 1 (FW1) project demonstrates the annual measurement results of wind kinetic energy. The measurements were conducted on masts lower than currently planned height of turbine nacelle fitting. In order to build a five-kilometer section of the power line connecting the wind farm with the transmission grid, the investor submitted the development rights. Both for power line area and for wind farm area there is no need to change the local zoning plans. For the wind farm area there is no environmental monitoring setup, and therefore there is no need for data on the probable risks linked to environmental conditions. Both local authorities and local community have positive attitude to the investment.

Wind farm 2 (FW2) has wind measurement results from the period of three years. The measurements were conducted on masts of approximately the same height as the previously planned height of the turbine nacelle fitting. For a short segment of the planned power line area it is necessary to change the use of agricultural land. On the planned power line route there is insufficient number of cadastral parcels whose owners are favorable to the investment. The wind farm area is located away from environmentally protected areas and within a safe distance from buildings. Environmental report was completed and investor made a preliminary study of social acceptance of the project.

5. RESULTS

Comparative analysis of projects with the application of F-AHP was commenced by comparing pairs of criteria affecting the implementation process of obtaining a planning permission for the construction of a wind farm. The results of the impact of the various criteria on the overall goal were shown in figure 2.

The comparison was made using pair-wise comparisons relative to each of the criteria and their weights were determined (tab. 2). F-AHP method used triangular fuzzy numbers to give judgments of the preferences of one criterion over another (tab. 1). The project having higher weight is more likely to fulfill the criterion.

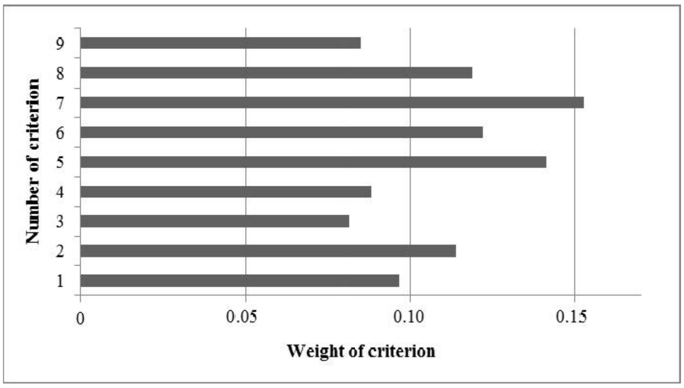

Fig. 2. The results of the impact of the various criteria to the overall goal

Tab. 2. Pair-wise comparison of wind farm projects FW1 and FW2

Number of criterion	Fuzzy assessment values for variants with respect to each criterion			Weight of criterion
	Symbol of project	FW1	FW2	
1	FW1	(1.00, 1.00, 1.00)	(0.20, 0.33, 1.00)	0.30
	FW2	(1.00, 3.00, 5.00)	(1.00, 1.00, 1.00)	0.70
2	FW1	(1.00, 1.00, 1.00)	(0.25, 0.50, 1.00)	0.33
	FW2	(1.00, 2.00, 4.00)	(1.00, 1.00, 1.00)	0.67
3	FW1	(1.00, 1.00, 1.00)	(1.00, 2.00, 4.00)	0.67
	FW2	(0.25, 0.50, 1.00)	(1.00, 1.00, 1.00)	0.33
4	FW1	(1.00, 1.00, 1.00)	(0.14, 0.20, 0.33)	0.00
	FW2	(3.00, 5.00, 7.00)	(1.00, 1.00, 1.00)	1.00
5	FW1	(1.00, 1.00, 1.00)	(0.25, 0.50, 1.00)	0.33
	FW2	(1.00, 2.00, 4.00)	(1.00, 1.00, 1.00)	0.67
6	FW1	(1.00, 1.00, 1.00)	(1.00, 2.00, 4.00)	0.67
	FW2	(0.25, 0.50, 1.00)	(1.00, 1.00, 1.00)	0.33
7	FW1	(1.00, 1.00, 1.00)	(0.17, 0.25, 0.50)	0.01
	FW2	(2.00, 4.00, 6.00)	(1.00, 1.00, 1.00)	0.99
8	FW1	(1.00, 1.00, 1.00)	(0.25, 0.50, 1.00)	0.33
	FW2	(1.00, 2.00, 4.00)	(1.00, 1.00, 1.00)	0.67
9	FW1	(1.00, 1.00, 1.00)	(1.00, 3.00, 5.00)	0.70
	FW2	(0.20, 0.33, 1.00)	(1.00, 1.00, 1.00)	0.30

Source: own study

Analyzing the problem of F-AHP method implementation was feasible using MS Excel spreadsheet. On the basis of pair-wise comparison ranking, criteria that affect the time to obtain wind farm planning permission were determined. As can be seen from the ranking (fig.2), predominant is criterion no. 7, i.e. to obtain environmental decision for wind farm area. It is associated with many factors that may cause the delay of the process of obtaining a decision, or to prevent its acquisition. In the next step, the importance of the projects to different criteria was indicated. Then importance of the projects in relation to their impact on the overall goal was computed. The analysis demonstrated that the FW2 project has a better chance of obtaining planning permission than FW1 project (tab. 3). It is associated with the predominant influence of the FW2 project on various criteria, e.g. for criterion no. 7 - of the highest impact on the overall goal achievement - FW2 received weight value of 0.15, with zero impact of FW1 project on the same criterion.

Tab. 3. Comparison of wind farm projects in terms of criteria

Symbol of the project	Number of criterion									Σ
	1	2	3	4	5	6	7	8	9	
FW1	0.03	0.04	0.05	0.00	0.05	0.08	0.00	0.04	0.06	0.35
FW2	0.07	0.08	0.03	0.09	0.09	0.04	0.15	0.08	0.03	0.65

Source: own study

6. CONCLUSION

Fuzzy Analytic Hierarchy Process (F-AHP) method was used to compare two wind farm projects. This is an issue of strategic importance to investors, because it allows the selection of the project that is more likely to be completed within a shorter period of time. It also allows for proper arrangement of tasks in the project groups in order to increase the chances of the project accomplishment, which turned out worse for the time required to obtain all the necessary decisions and permits to obtain a construction permit.

F-AHP method helped to determine the advantage of one project over another. Despite its being time-consuming, the authors conclude that the method is useful for solving this type of localization problems. Conversely, one of the drawbacks of this method is its heavy dependence on expert judgment. In the analyzed case the authors worked with a team of experts who deal with the implementation of wind farm projects every day. Therefore, the case of the lack of expert judgment, arising from their incomplete knowledge, was not analyzed.

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WIELOKRYTERIALNE WSPOMAGANIE DECYZJI INWESTYCYJNYCH W SEKTORZE ENERGETYCZNYM Z ZASTOSOWANIEM ROZMYTEJ METODY ANALIZY HIERARCHICZNEJ (F-AHP)

Referat przedstawia porównanie projektów dwóch farm wiatrowych. Tego typu analiza znajduje zastosowanie w przypadku zakupu projektów inwestycyjnych będących w fazie przygotowania. Spowodowane jest to koniecznością uwzględnienia wymogów określonych w ustawodawstwie polskim. Porównanie projektów budowy farm wiatrowych oparto na analizie zaawansowania oraz priorytetu poszczególnych etapów inwestycji. Aby zweryfikować, na jaki etap należy zwrócić szczególną uwagę posłużono się analizą zagadnień opisujących poszczególne etapy oraz zadań w nich realizowanych. Zagadnienia te definiują kryteria wpływające na realizację projektu. Analizę przeprowadzono z wykorzystaniem metody F-AHP, która pozwala na ilościowe i jakościowe uporządkowanie kryteriów. Analiza wykazała, że priorytetowym kryterium jest uzyskanie decyzji o uwarunkowaniach środowiskowych dla obszaru farmy wiatrowej oraz to, że projekt FW2 maj większe szanse na realizację niż projekt FW1.

Słowa kluczowe: Fuzzy Analytic Hierarchy Process, farma wiatrowa, proces inwestycyjny.