Multi-Dimensional Factors Analysis of Wind Farm Site Selection Using Fishbone Analysis and Interpretive Structural Modeling Method

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Keywords: Wind farm site selection, Fam, Multi-dimensional influence factors, Ism

Abstract: The final location of wind farms is affected by plenty of factors, and each factor restricts and influences each other, thus forming a complex multi-dimensional impact system. Therefore, it is necessary to study how each factor affects the location of wind farms. Through the Fishbone Analysis Method (FAM), the multi-dimensional influencing factors of wind farm location choice are analyzed, and on this basis, an interpretative structure model (ISM) of multi-dimensional influencing factors is constructed. The key influencing factors and basic influencing factors that affect the location of wind farms are obtained. The hierarchical structure relationship diagram, and systematically and comprehensively analyze the influence degree and influence path of these influencing factors on the geographical location of wind farms, thus providing a more feasible way for choosing the applicable location of wind farms.

1. Introduction

In the contemporary, the wind farm industry is developing at a rapid rate in China. The construction of wind farms is constantly developing towards scale and standardization. As the primary key link of wind farm construction, the site selection of wind farms is directly correlated to the investment, construction, operation and maintenance of wind farm, and plays a significant role in value creation and value-added. Therefore, it is very important to study the influencing factors of wind farm site selection.

Many experts at home and abroad have carried out relevant research on micro-site selection, including micro-site selection factors and micro-site selection methods. Liu used the improved binary firefly algorithm to optimize the micro unit arrangement of wind farm after the macro position has been selected [1]. Javier Serrano González believed that when selecting an offshore wind farm site, it is necessary to analyze the economic indicators, environmental issues, local regulations and other aspects from the micro perspective, and they summarize the current work [2]. As for site selection planning for offshore wind farms. The national scholar Tan Maoqiang took wind farm wake reduction coefficient, offshore line investment as optimization goals, and establishes a multi-objective optimization decision-making model for offshore wind farms by improving the Pareto multi-objective optimization algorithm [3]. A two-level optimization approach was introduced by Mengxuan Song for three-dimensional micro-siting optimization of large-scale wind farms to reduce the difficulty of searching for the optimal solution [4]. Parada, L proposed a high-efficiency wind farm design method to plan the micro-site layout of wind farm sand this method maximizes the power of wind farms [5]. Through the research of these literatures, we found that the micro-site selection of wind farms is mostly the planning of the layout of wind farms, and there are relatively a small amount of studies regarding the specific location of wind farms. In terms of macro-site selection, many scholars have also conducted certain research. Yun-na, W used Matter-Element Expansion method and Ideal Matter-Element Expansion method to evaluate the site selection of hybrid renewable energy power stations [6]. Atici K B proposed to use multi criteria decision analysis to make decisions on the site selection of wind farms in both macro and micro perspectives [7]. There are also relatively little literatures on the site selection of wind farms from a macro perspective. The macro-site selection research needs to be expanded and supplemented to a certain extent.

  DOI: 10.25236/cseem.2020.028

In addition, many scholars have conducted research on the site selection of wind farms and wind farm-related industries based on specific influencing factors. Xu Peidong applied intelligent algorithms to the location and capacity of decentralized wind farms, then considered wind power consumption and power flow balance as key factors [8]. Gualtieri, G took the wind turbine model as the key factor, adopted a detailed cost model, took the energy leveling cost as the main targeting function, and the capacity factor as the secondary targeting function. The self-organizing map was used to conduct in-depth scrutiny to optimize the layout of wind farms [9]. Tang Zhengqi established a fuzzy inference engine from four aspects of wind energy resources, natural environment, traffic environment and wind turbine conditions, and constructed its fuzzy inference rules to find the optimal location of wind farms [10]. Chen Kaizheng believed that the booster station is a crucial part of the wind farm site selection, and based on the 3D GIS technology AHP was used to assess and decide the wind farm booster station site selection from five aspects [11]. Lip-Wah Ho used the international Delphi method to summarize the wind farm site selection from four aspects: profitability, society, security and social factors [12]. Chu Zhuang comprehensively considered the hourly wind turbine output efficiency to construct an hourly field, based on the improved K-means clustering method, the average value of the wind turbine output efficiency of each scene was clustered, and took minimum annual cost as the objective function, the improved genetic algorithm was used to determin the location and capacity of distributed wind power generation [13]. Throughout the research and studies of wind farm site selection by domestic and foreign scholars, it is found that most scholars choose relatively few influencing factors when analyzing the factors affecting wind farm site selection, a which can't comprehensively reflect the influence degree of various factors on wind farm site selection. Moreover, AHP and grey correlation degree are often used in the method, which has strong subjectivity. This paper chooses to use FAM and ISM to analyze wind farm site selection. FAM can clearly list the distribution of multi-dimensional influencing factors in wind farm site selection, and ISM can avoid subjectivity and contingency to a certain extent. It also reflects the relationship and structural of multi-dimensional wind farm site selection. In this paper, we construct FAM-ISM to solve the wind farms site selection. The main contributions of this paper are stated as the follwing:

(1) According to the comprehensive literature review, FAM-ISM is rarely used in the wind farms site selection. By optimizing the site selection of wind farms, value-added can be realized.

(2) In this paper, the FAM is used to analyze the influencing factors of wind farm site selection. ISM is constructed to obtain the main influencing factors secondary, influencing factors and hierarchical structure diagrams that affect wind farm site selection.

(3) The paper FAM-ISM is used to systematically and comprehensively analyze the influence degree and influence path of these factors on the site selection of wind farm, so as to provide a feasible idea for the site selection of wind farm.

2. Fam of Wind Farm Site Selection Factors

2.1 Principles for Site Selection of Wind Farms

Both the selection of wind farms on the micro, as well as the macro, perspective should follow certain principles.

(1) Rationality principles. The location of wind farms should be selected in areas with high-quality wind energy resources, and make a reasonable plan for the location and quantity of wind turbines to meet the planning and requirements of the national power grid.

(2) Strategic principles. It is essential to contemplate the operation of the wind farm after its completion, the possibility of expanding the wind farm, as well as the formation and advancement of the entire wind power industry chain after the wind farm is completed.

(3) Scientific principles. Found on the investigation results of wind energy resources, select the area with the greatest possibility of wind energy acquisition. Raise the output of wind power, and improve the economics, convenience and scientificity of power supply.

(4) Controllability principles. When choosing sites for a wind farm, you must fully consider the local government's policies and the long-term land occupation amount should be specified. If possible, choose to use wasteland and bad land away from the crowd to reduce the possibility of personnel relocation and avoid large village relocation. Minimize the operating costs of wind farms.

(5) Coordination principles. The site selection of wind farms should pay attention to the coordination with regional transportation; The coordination with regional infrastructure, including the coordination of power communication facilities, water supply and drainage systems, also including the coordination of heating and ventilation.

(6) Importance principles. The feasibility and necessity of local wind farm construction should be fully investigated before the wind farm site selection, and the importance of the establishment wind farms to the local area can be obtained through the investigation.

(7) Environmental protection principles. The site selection of the wind farm should pay attention to protecting the surrounding environment, not damaging the normal ecological cycle of the surrounding animals and plants, minimizing impact of wind power on the bird's living environment, and reducing the impact of noise on the surrounding residents.

2.2 Fam

Combined with the above principles, this paper uses FAM to analyze the multi-dimensional influencing factors of wind farm site selection. FAM was first proposed by Professor Ishikawa Xin, a management master of Tokyo University in Japan. It is called fishbone diagram because of its fishbone shape. It is also called cause and effect diagram, which is an innovative analysis method to find the root cause of the problem.

There are many elements affecting the site selection of wind farms, mainly from the following six dimensions to analyze the influencing factors:

(1) Institutional dimension, including industrial policies, relevant legal system, subsidy policies of wind power industry, etc.

(2) Geographical dimension, including the availability of wind energy, surface stability, hydrogeology, topographical conditions and surface bearing capacity, etc.

(3) Environmental dimension, including soil and water conservation investment, energy conservation and environmental protection investment, pollution reduction benefits and land occupation, etc.

(4) Economic dimension, including investment profit rate, investment payback period, planned investment amount and financing capacity of wind farm, etc.

(5) Technical dimension, mainly including wind farm construction cycle, equipment life cycle, R&D capacity and coordination with infrastructure;

(6) Human resource dimension, including personnel education and training, learning ability of staff, etc.

3. Ism of Wind Farm Site Selection

According to the analysis of the multi-dimensional influence fac progressive tors of wind farm site selection based on the above FAM, the hierarchical relationship between the factors are identified and analyzed by constructing the multi-dimensional influence factors interpretation structure model of wind farm site selection.

ISM was developed by Professor J. Warfidell of the United States in 1973 as a method for analyzing the problems related to the complex social and economic system [22]. Its characteristic is to decompose the complex fuzzy large-scale system into several subsystems or factor factors. With the help of people's practical experience, knowledge, and electronic computers, the elements of subsystems and their order can be determined comprehensively. It can be applied at all stages of system engineering to clarify problems, determining objectives, planning, analysis, synthesis, evaluation and decision-making, especially for unified opinions. This paper uses ISM to explore the hierarchical relationship between the multi-dimensional influencing factors of wind farm site

selection, looking for the fundamental and key factors that affect wind farm site selection among multi-dimensional influencing factors.

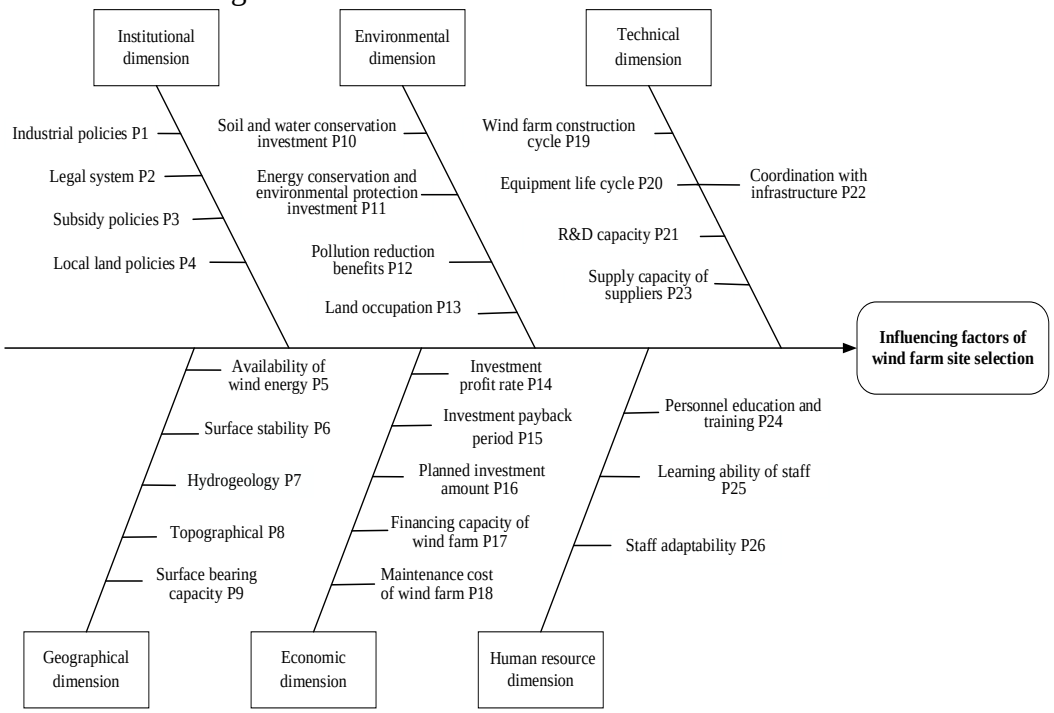

Fig.1 Fam of Influencing Factors of Wind Farm Site Selection.

3.1 Construct the Adjacency Matrix

In order to get a more reasonable adjacency matrix, this paper uses the expert scoring method, inviting fifteen experts to score, and they don't communicate with each other. In the scoring results, if more than two-thirds of the experts believe that there is a direct influence relationship between two factors, then the two factors are judged to have a direct influence relationship; otherwise, they are deemed to have no direct influence between two factors. Finally, a comprehensive evaluation is carried out to determine the most direct relationship between the factors of wind farm site selection. According to the following rules, the direct correlation between each influencing factor is constructed, and the adjacency matrix P in the first step is generated, as shown in eq (1).

If P_i has a direct impact on P_j, then the value of p_{ij} is 1. If P_i has no direct effect on P_j, then the value of p_{ij} is 0.

$$P=\begin{bmatrix}
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
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0&0&0&0&1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&1&0&0&1&0&0&1&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&1&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0
\end{bmatrix}\qquad(1)$$

3.2 Solve Accessibility Matrix and Its Reduction Matrix

Based on the given adjacency matrix, the accessibility matrix can be further calculated. The solution of accessibility matrix R satisfies the power multiplication of adjacency matrix A and identity matrix I, that is, the eq (2) is satisfied.

$$R=(A+I)^{n+1}=(P+I)^{n}\neq(P+I)^{n-1}\neq\ldots\neq(P+I)^{2}\neq(P+I)\qquad(2)$$

Eq (2) is the power calculation through Boolean operation, which is solved by MATLAB to get $n=5$, and the accessibility matrix R is obtained. The accessibility matrix R is shown in eq (3).

Among them, $r_{ij}=1$ means that if P_i has a direct or indirect effect on P_j; if $r_{ij}=0$, it means that P_i has no effect on P_j.

From the accessibility matrix R, we observe that the rows and columns corresponding to P10, P13, P11, P12, P16, P17, P21 and P25 are completely consistent, so we keep P10, P11, P16, P21. and reduce the accessibility matrix to obtain the reduced matrix. By reducing the accessibility matrix R, the reduction matrix R_1 is obtained. The reduction matrix is shown in eq. (4).

$$R=\begin{bmatrix}
1&0&1&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
1&1&1&1&1&0&0&0&0&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&1&1&0&0&0&0&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&1&1&1&0&0&1&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
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0&0&0&1&1&0&0&0&1&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
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0&0&0&0&1&0&0&0&0&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0\\
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1&0&1&0&0&0&0&0&0&0&1&1&0&0&0&1&1&1&0&1&1&1&1&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&1&0&0\\
1&0&1&0&0&0&0&0&0&0&1&1&0&0&0&1&1&1&0&1&1&1&1&1&0\\
1&0&1&0&0&0&0&0&0&0&1&1&0&0&0&1&1&1&0&1&1&1&1&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&0&0&1&0&0&0&1
\end{bmatrix} \quad (3)$$

$$R_1=\begin{bmatrix}
1&0&1&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
1&1&1&1&1&0&0&0&0&1&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
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0&0&0&1&1&1&0&0&1&1&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&1&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&1&0&1&0&0&0\\
1&0&1&0&0&0&0&0&0&0&1&0&0&1&1&0&1&1&1&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&1&0&0\\
1&0&1&0&0&0&0&0&0&0&1&0&0&1&1&0&1&1&1&1&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&0&0&1&0&0&1
\end{bmatrix} \quad (4)$$

3.3 Ism of Influencing Factors Affecting Wind Farm Site Selection

In order to understand the hierarchical relationship between the influencing factors of wind farms site selection more clearly, the hierarchical division is the key step to establish a multi-level interpretation structure model. After dividing different levels, the hierarchical structure model of wind farm site selection influencing factors can be obtained, the specific hierarchical division process is based on eq. (5).

$$L(P_i)\bigcap D(P_j)\neq\varnothing \quad (5)$$

Among them, 1 and 2 are the specific factors affecting the site selection of wind farms above, 3 is the reachable set of the model, that is, the collection of element 1 itself and all the factors that can be reached; 4 is the prior set in the model , that is, the collection of element 2 itself and all the factors that can be reached; this formula means that 1 and 2 belong to the same level. The result of hierarchical division based on reduction matrix R_1 is shown in Fig. (2).

4. Analysis of Ism

From the ISM of the factors affecting the wind farms site selection, we can see that the application of ISM is conducive to the analysis of these factors in an orderly and hierarchical way.

(1) Energy conservation and environmental protection investment, planned investment amount, pollution reduction benefits and wind farm financing capacity are the most direct factors that have effects on the site selection of wind farms. the impact of energy conservation and environmental protection investment and pollution reduction benefits on the site selection and construction of wind farms are very significant. The planned investment amount and the financing scope of the wind farm reflect the influence of capital flow on the site selection factors of the wind farm. Sufficient capital is the foundation for supporting the construction of the wind farm and also a necessary support for the construction of the wind farm.

(2) The government's subsidy policy, coordination with infrastructure, availability of wind energy, investment profitability, investment payback period and supplier's supply capacity are the main factors that influence the site selection of wind farms. It is obvious that the availability of wind energy contributes a huge impact on the site selection of wind farms. Having high-quality wind energy conditions can directly affect the planned investment amount and the financing capacity of the wind farm, which provides a powerful support for site selection and later construction of wind farm. Good coordination with infrastructure can reduce investment in this area and increase investment in other aspects. The government's subsidy policy, investment profit rate and investment payback period also reflect the impact of economic ability on wind farm site selection. Higher investment profit rate and shorter investment payback period attract more investors to invest and promote the construction of wind farms.

(3) Industrial policies, hydrogeological conditions, investment in soil and water conservation, land occupation and wind farm maintenance costs are the key factors affecting the site selection of wind farms. If the site chosen for the wind farm is not appropriate, it will cause higher costs for the maintenance of the wind farm and occupy other costs, this will impose a heavy burden on the effective operation of wind farms. So, when choosing a site, it is necessary to consider whether the site is suitable for building a factory,. We need to ensure that the wind farm can have a stable and long-term large-scale land for construction.

(4) The construction timespan of the wind farm also needs to be well planned. If the construction timespan of the farm is too long, it will negatively impact the future revenue of the wind farm. The life cycle of wind power equipment affects the wind farms site selection by affecting the operating and maintaining costs of wind farms.

(5) R & D capability, personnel education and training, staff learning ability, surface stability and legal system are the most basic elements that affect the site selection of wind farms. From ISM, it can be seen that R&D capability can affect a lot of factors, and the site selection of wind farms can be affected by these factors. Staff training and education are equally important. Staff education and training can affect their learning ability and R&D capability.

5. Conclusion

This paper discusses many factors that could affect the site selection of wind farms. By constructing ISM of the factors influencing the wind farms site selection, it analyzes the correlation between the various influencing factors, and clearly shows the hierarchical structure of each factor. Based on the obtained ISM, we can know that the investment of funds and the environmental benefits are the most critical factors for the site selection of wind farms. Therefore, we need to increase its investment of funds, promote the further development of pollution reduction benefits, improve the financing capacity of wind farms, and provide sufficient financial guarantee for the follow-up technology introduction, research and development and energy storage technology development. At the same time, we should also pay attention to the dynamic development of industrial and subsidy policies. In the genesis of wind farm construction, detailed policy investigation on the target site is carried out to fully understand the clean energy consumption policy and grid connection policy in the local industrial policy. The greater the demand for clean energy in the policy, the stronger the ability to consume clean energy, and the more beneficial it is

to the construction, later development and maintenance of the farms. Finally, staff education and training, scientific research capabilities, and legal systems are the most basic factors influencing the site selection of wind farms. We are reminded that when selecting sites, we must pay attention to the quality and ability of staff, improve the scientific research ability of scientific research personnel, understand the complete legal system of wind farm operation, create a good human resource foundation and a comprehensive policy foundation for wind farm site selection.

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