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Study of decision framework of offshore wind power station site selection based on ELECTRE-III under intuitionistic fuzzy environment: A case of China

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ABSTRACT

Offshore wind power projects have been rapidly proposed in China due to policy promotion. Site selection immensely decides the success of any offshore wind power development and is a complex multi-criteria decision making (MCDM) problem. However, canonical MCDM methods tend to fail the site selection process due to the following three problems. Firstly, the compensation problem exists in information processing. Secondly, there exists the problem of incomplete utilization of decision information and information loss in the decision process. Thirdly, the interaction problem in the fuzzy environment is easy to be ignored. To deal with the above problems, this study builds a framework for offshore wind farm site selection decision utilizing Elimination et Choix Traduisant la Realité-III (ELECTRE-III) in the intuitionistic fuzzy environment. First of all, the comprehensive index system of OWPS site selection consisting of veto criteria and evaluation criteria is constructed. Then, the intuitionistic fuzzy set is used in the group decision for the decision makers to express the imperfect knowledge. Moreover, the generalized intuitionistic fuzzy ordered weighted geometric interaction averaging (GIFWGIA) operator is applied to deal with the interaction problem. Together with the likelihood-based valued comparisons, imprecise decision information is reasonably used and information loss problem is rationally avoided. Then a case of China is studied based on the proposed framework, demonstrating the site selection methodology valid and practical. This study implements evaluation method for offshore wind power site selection and also provides a theoretical basis for the development of offshore wind power decision-making in China.

1. Introduction

In recent years, developing renewable energy in China has become an important step to achieve natural energy goals. In economically developed eastern coastal cities of China, demands for electricity grow rapidly. The desire of Chinese government for developing offshore wind farm resources is strong due to local offshore wind. The offshore wind power planning target till 2015 is 5 million kW, however, the target completion rate is less than 1/10 till 2013. Many projects are required to suspend or relocate because of wrong site selection problems.

The offshore wind power station (OWPS) site selection is a critical step toward a successful wind power project. It is a multi-criteria decision making (MCDM) problem, concerning conflicting criteria involving offshore wind resources, the environment, sea area planning, power grid access lines, economy, society, etc. In last two years, imperfect consideration concerning these aspects have hold back the development of OWPS, as is shown in Fig. 1. At present, studies such as development of offshore wind turbines and wind power integration are widely performed in China, but studies on offshore wind farm site selection are scarce. Offshore wind farm site selection studies have been conducted outside by many researchers. Vafaeipour et al. [1] presents a hybrid MCDM approach to identify suitable regions for implementation of future solar power plants. Uyan [2] proposes AHP model to select a suitable site for nuclear power plant. Shafiee [3] Studies on selecting appropriate risk mitigation strategy for offshore energy projects with ANP method. Choudhary and Shankar [4] propose TOPSIS method for evaluation and selection of optimal locations for thermal power plant. It can been seen that MCDM approaches provide effective framework for renewable energy plant selection with multiple conflicting criteria. However, there are still many problems in the existing decision process for OWPS

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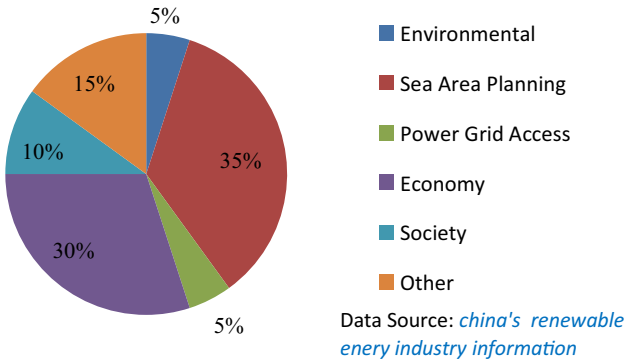

Fig. 1. Planning problems hold back OWPS construction in china.

site selection, which makes current decisions hardly conform to the real situations.

(1) Firstly, vagueness generally exists in OWPS site selection decision problems. On one hand, site selection decision happens before the construction of OWPS, so the evaluation information is often hard to predict accurately or quantified precisely due to the complex situation with respect to OWPS and unforeseen factors. On the other hand, for decision makers (DMs), the practical judgments are often vague; neither the level of satisfaction nor the degree of dissatisfaction can be accurately estimated. That is to say, the site selection decision is under the imperfect and incomplete information environment. Therefore, determining how to express judgments integrally and sufficiently is a problem facing OWPS site selection.

(2) Secondly, the compensation problem exists in some canonical MCDM approaches, such as weighted synthesis method. As a result, for some alternatives, it may occur that the good performance in some criteria can make up for the poor performance in other criteria. That is to say, for instance, some site alternatives may have very poor scores in some criteria such as serious influence on the environment though, their superiority in other criteria like wind resources and construction conditions is magnificent. They still could rank at the top because of compensation problems; while some alternatives, which may work fine on every respect, are likely to be eliminated.

(3) Thirdly, incomplete utilization of decision information and information loss exist in the process of OWPS site selection decision, which could in turn give rise to decision failure. It mainly happens in the comparison stage in deciding the preferable plan of each pair of alternatives under multi-criteria, for there is a lack of feasible mechanism to distinguish different levels of preference. Although the existing outranking methods like ELECTRE-III has advantages in constructing preference degrees of real numbers by using valued outranking relations, it still needs to be extended in real-world applications to handle ambiguous information. Preference judgments need to be rationally processed to ensure the quality of decision-making under incomplete information environment.

This study aims at establishing a practical index system for OWPS site selection and developing an effective comprehensive evaluation framework to select the most satisfactory plan. We propose a new design of comprehensive MCDM framework based on the ELECTRE method to handle the OWPS site selection problems in the presence of multiple decision makers under incomplete information environment. To begin with, the comprehensive index system of OWPS site selection consisting of criteria and sub-criteria is constructed on the basis of experts consulting and literature analysis. In accordance with the evaluation criteria and veto factors, the potential competition sites can be identified. An integrated weight method is adopted for DMs to measure the relative importance of multiple criteria. The intuitionistic fuzzy numbers and linguistic variables are used for DMs to indicate the degree of satisfaction and dissatisfaction of the potential sites with respect to each criterion. Following this, the generalized intuitionistic fuzzy weighted geometric interaction averaging (GIFWGIA) operator is applied to integrate the DMs' evaluation on alternatives rating and criteria weights. Afterwards, the likelihood-based outranking relationship is proposed to define the indifferent, the strong preference and the weak preference relations by performing pairwise preference comparisons between the intuitionistic fuzzy numbers. A new concordance and discordance analytical measure is developed for providing partial and complete ranking orders. The MCDM framework of OWPS site selection in this study, provides insightful information for the managers to analyze and select the optimal site for OWPS decision-making. It is proposed for the following reasons.

- To handle the vague and imprecise information of the real world, the fuzzy set is normally utilized. Compared with Zadeh's traditional fuzzy set, Atanassov's intuitionistic fuzzy numbers convey more information for situation expression, including membership, non-membership and hesitation degree [5]. The intuitionistic fuzzy sets (IFSs) are proved to be more effective in dealing with inevitably imprecise or not totally reliable judgments, which is suitable for DMs to express their affirmation, negation and hesitation in decision-making applications [6–8]. Recently, the IFSs have aroused increasing concern and been widely performed in MCDM problems, revealing the capacity of handling the incomplete information [9–13].
- The compensatory problem is reasonably processed by the ELECTRE method. Different from fully compensatory methods such as TOPSIS, ELECTRE is partially compensatory, which means a severely dissatisfactory score with respect to a criterion would not be compensated by other content criterion rates, which conforms to the reality situations [14,15]. The ELECTRE method uses the outranking relation mechanism to handle decision information. The ranking order is determined by comparing the merits of every two attribute values, which counteract the effect of inaccurate attribute values on overall program to some extent, thus drawing a reasonable sorting results [16].
- The information loss is effectively avoided and important basic knowledge is reasonably utilized by adopting the valued outranking relations and the likelihood-based pairwise comparisons. We uses ELECTRE-III rather than ELECTRE-I and ELECTRE-II because it constructs reasonable binary relations without sacrificing information. In addition, the likelihood-based comparison is used as it fully utilized the various aspects of fuzzy information. Therefore, the integration of the valued outranking relation and the likelihood-based pairwise comparisons has more advantages in obtaining reasonable outranking relations in the fuzzy and imprecise environment.

2. Literature review

Multi-criteria decision making (MCDM) methods, such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Elimination et Choix Traduisant la Realité (ELECTRE), are widely used by decision makers in the energy field. Lee et al. [17] use AHP to measure the relative efficiency of energy technologies. Kaya and Kahraman [18] study on a