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A cloud decision framework in pure 2-tuple linguistic setting and its application for low-speed wind farm site selection

Yunna Wu [a], Kaifeng Chen [a, *], Bingxin Zeng [b], Meng Yang [a], Lingwenying Li [a], Haobo Zhang [a]

[a] School of Economics and Management, North China Electric Power University, Beijing, China
[b] School of Economics and Management, Beihang University, Beijing, China

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ABSTRACT

Low-speed wind farm site selection is crucially important for investment returns. However, three great problems reducing the decision-making accuracy and restricting applications exist in the present multiple criteria decision analysis. Firstly, the uncertainty of information fails to be fully described, without considering its randomness. Secondly, during dimensionless treatment and normalizing, some information distortion and loss are caused when evaluating the differences among criteria values just from a mathematical standpoint. Thirdly, the managers are excluded from the decision-making process, which decreases the practicality and operability, and considerably restricts the application of the decision-making methods at the same time. In order to overcome these deficiencies, a cloud-based decision framework under pure 2-tuple linguistic environment is proposed for low-speed wind farm site selection in this paper. First, the criteria values are transformed into 2-tuple linguistic through dimensionless treatment and normalizing; then the extended golden section method is used to transform 2-tuple linguistic into cloud variable. Next, a pure cloud weighted arithmetic averaging operator is constructed to rank the alternatives. After that a case from China is presented to demonstrate the effectiveness. Finally, the comparison analysis and sensitive analysis are conducted, proving the correctness and advantages of the proposed decision framework.

1. Introduction

Over the recent years, low-speed wind farm (LSWF) has become a focus in the field of new energy as well as an investment upsurge in China. Three main factors can explain this phenomenon: (i) Environmental pressures caused by the thick haze (Liu et al., 2016) and the challenging commitment made by the Chinese government at the Copenhagen Conference. (ii) Technology innovations. Due to the government's supportive policies, China's wind power industry has made substantial progress during the Twelfth Five-Year Plan. (iii) Distorted energy demands. China's "three northern areas" (referring to Inner Mongolia, Gansu and Northern Hebei Province) are far away from the load center with weak power grids. Additionally, the still-tight policy for nuclear power and limited hydropower (Huang and Yan, 2009) also contribute to the development of LSWF.

Site selection is one of the common and yet important problems in the energy field. Unlike other operation factors, locations cannot be changed after confirmation due to their fixation and longevity. Whether the site for LSWF is appropriate will significantly impacts on the benefit, expansion and development in the future, even success of wind farms. However, the extant research mainly focused on the efficiency of the wind turbine. Thus, this paper can fill a gap in the research on site selection. Actually, LSWF site selection involves a complex and long task by evaluating and selecting the optimal one through comparing the alternatives against a series of qualitative or quantitative criteria, which can be characterized as a multiple criteria decision making (MCDM) problem. Therefore, an appropriate decision method should be selected for gaining more accurate and reliable results.

However, some problems are not be considered or solved in the current MCDM methods. (i) The uncertainty of criteria values and criteria's weights failed to be fully described during decision making process. Currently, fuzzy set and 2-tuple linguistic are introduced to describe the uncertainty by using fuzzy numbers and

* Corresponding author.
E-mail address: ckfhdchina@126.com (K. Chen).

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2-tuple linguistic variables instead of numerical values to represent the experts' preferences, but they just consider the fuzziness, completely ignoring the other side of the uncertainty, namely randomness. (ii) Some information distortion and loss exist in dimensionless treatment and normalizing process. The quantitative variation is exclusively focused on, without considering qualitative change, which may lead to misunderstanding and distortion. For instance, the lending rates of the alternatives are 7%, 8% and 9% respectively, which seems to be closed quantitatively but has disproportionate impacts on investment income yet. Relative comparisons are mainly carried on for comparing the performance values among different alternatives instead of absolute comparison, which will make such the situation: the highest one can be identified, but its height is unknown. For managers, it's difficult to comprehensively analyze strengths and weaknesses and acquire the improving direction of the selected alternative. (iii) Many existing MCDM researches stay at the theoretical level by mainly emphasizing on how to model and evaluate the alternatives. However, the real-world decision is far from that. Decision makers who are behind the decision-making process are neglected. That is to say, the previous studies cannot be directly incorporated into the project management, owing to lack of practical operability.

According to the above analysis, this paper proposes a cloud-based decision framework under pure 2-tuple linguistic environment for LSWF site selection integrating ideas of management. The main contributions can be shown as follows: Firstly, during the information processing, the proposed decision-making framework can effectively avoid the loss and distortion of information through giving consideration to both fuzziness and randomness. Secondly, the performance value and corresponding importance weights are assessed by using linguistic form instead of crisp values, which enables the decision makers to express their preferences and opinions accurately and conveniently. Thirdly, as to the performance of one criterion, the differences among alternatives are evaluated through full attention to its actual connotation, rather than considering the differences among criterion values as the only judgment standard. This conforms better to the actual situation and makes the decision results more accurate. Fourthly, the proposed decision-making framework combs the site selection process of LSWF as well as the responsibility and tasks of managers, which contributes to understanding and further improving management efficiency for practitioners.

The remainder of this paper is organized as follows. Section 2 presents a literature review on current site selection methods. The research methods are described in Section 3. Section 4 presents the decision-making framework for LSWF site selection. In Section 5, the applicability of the proposed model is demonstrated through the site selection of five alternatives in the giant 'J' Corporation. The results and discussion are shown in section 6. Subsequently, the final conclusion and future research are provided in Section 7.

2. Literature review

Site selection methods will influence the accuracy and reliability of the decision results on great degree. Many decision-making approaches for site selection have been introduced in current studies. Among them, a number of studies have applied analytic hierarchy process (AHP) method individually or comprehensively in site evaluation. Wu and Geng (2014) and Rezaian and Jozi (2016) used it for the selection of solar-wind hybrid power station location and wind farm respectively; Khan and Samadder (2015) utilized AHP to evaluate the most environmentally suitable landfill sites (Sanchez-Lozano et al., 2016a); combined AHP with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and ELimination and Choice Expressing Reality (ELECTRE) respectively to select the optimal sites for photovoltaic solar farms.

The above researches employ the crisp value to express the preference in the evaluation process, causing much information loss. The application of fuzzy set is recommended to overcome the situations where crisp value fails to describe the criteria values and criteria's weights. The analytic network process (ANP) and fuzzy TOPSIS were integrated to determine the weights of the criteria and obtain final priorities of tourism sites (Morteza et al., 2016). Also, with the extension of classical fuzzy set, various fuzzy decision methods for site selection have been brought forward and applied. Sanchez-Lozano et al. (2016b) integrated triangular fuzzy numbers into AHP and TOPSIS for site selection of onshore wind farm. Trapezoidal fuzzy numbers was combined with the extended VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) method to deal with the site selection problems in municipal solid waste management (Liu et al., 2014a). Intuitive fuzzy set is an extension of traditional fuzzy set and is well suited to deal with these the vague preference information and incomplete knowledge of different interest groups, for example, wind farm project plan selection (Wu et al., 2014b). Hesitant fuzzy is very useful in handling decision problems defined under uncertainties where decision makers hesitate among several values before expressing their preferences, for instance, hospital site selection (Senvar et al., 2016).

Seen from the above review, fuzzy set theory is common used to solve site selection problems instead of crisp values by combining with traditional evaluation approaches, such as AHP, TOPSIS, ELECTRE, VIKOR and so on. To some degree, fuzzy numbers contributes to reducing the uncertainty by giving more accurate and suitable expression. However, the information loss continues to be a significant problem. Since site selection involves both quantitative and qualitative indicators, fuzzy numbers will cause uncertainty from the presupposed membership function (Wang and Fan, 2003) when describing the linguistic evaluation information. To solve the problem, it seems effective to directly compute with words instead of transforming them to fuzzy numbers or crisp values. Unfortunately, the traditional linguistic assessment sets are discrete. Actually, 2-tuple linguistic variables can breakthrough both limitations. Some researchers have employed it to model and manage uncertainty, which has given good results and implied the accomplishment of processes of computing with words. Zhang et al. (2010) combined 2-tuple linguistic with the Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) to rank the contaminated sites. Liu et al. (2014b) proposed an attitudinal-based interval 2-tuple linguistic VIKOR method. The method incorporating the uncertain and incomplete assessment information proved to be suitable and effective for solid waste site selection. For site selection problems, the 2-tuple linguistic can reduce the information loss effectively compared with fuzzy set and crisp values. However, just as fuzzy set, the 2-tuple linguistic does not take the randomness into consideration, either. Cloud model, considering both fuzziness and randomness, can overcome that defect.

Meanwhile, dimensionless and normalizing process can exert an influence on the final results. Some studies ignored the actual connotation of criteria. Dong et al. (2014) used ELECTRE-II for the macro-site selection of wind/solar hybrid power station, with non-dimension of the date just considering mathematical level. The same was true for the literature (Latinopoulos and Kechagia, 2015). Practically, performance values at different stages of development could result in a disproportionate level of influence. Thus, the real difference may be misunderstood and distorted if the differences among them are viewed from the angle of purely mathematics. Additionally, the absolute comparison can help managers to comprehensively analyze strengths and weaknesses and acquire