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Sustainable site selection for photovoltaic power plant: An integrated approach based on prospect theory

Hong Fang[a], Jing Li[a], Wenyan Song[a,b,*]

[a] School of Economics and Management, Beihang University, Beijing 100191, China
[b] Key Laboratory of Complex System Analysis, Management and Decision (Beihang University), Ministry of Education, Beijing 100191, China

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ABSTRACT

Site selection is one of the critical steps in building photovoltaic power plants which influences electricity-generating capacity and socio-economic benefits in the future. It needs to consider many factors in site selection, such as climate, geology, and social acceptance, etc. Thus, photovoltaic power plants site selection is a complex problem of multiple-criteria decision-making. However, most of the previous studies consider less about the subjectivity and vagueness of decision-making information and assume that decision makers are totally rational without considering their psychological factors. To deal with the problem, a novel integrated method based on variable precision rough number, Technique for Order Performance by Similarity to Ideal Solution and prospect theory is developed in this paper. Basically, the method includes two stages: one is determination of criteria weights based on variable precision rough number, and the other is selecting the most suitable photovoltaic power plant site with a prospect theory-based approach. The novel method integrates the advantage of variable precision rough number in flexibly dealing with vague information and the merit of prospect theory in manipulating decision maker's bounded rationality. Finally, a case study of a 10-megawatt photovoltaic power plant site selection in China is used to demonstrate the effectiveness and efficiency of the proposed method.

1. Introduction

Global warming, energy security and economy issues force the switch from traditional energy to new energy [1]. Solar energy has been proven to be one of reliable new energy resources to generate electricity. Solar energy is abundant, free and clean, and it does not make any noise or any kind of pollution to the environment [2]. To make use of solar energy for industrial purposes, it has been extracted through many attempts. The photovoltaic (PV) system is one of the main categories of solar energy industrial applications. With the advances of photovoltaic technology and reduction of manufacturing costs [3], the photovoltaic power plant (PVPP) has come to stay. A number of studies focus on the problems of PVPP, e.g., comparisons with other solar power plant projects [4], life cycle assessment and evaluation [5], sensitivity and reliability of photovoltaic systems [6], solar PV plants' performance [7], and sustainable PV module supplier selection [8]. For a solar energy company, a critical step is to identify and prioritize suitable sites for PV power plants to obtain the optimal production and payback [9], because climate and land use change influence potential electric power generation [10]. For example, Marion et al. [11] compared the energy production of PV modules located in Florida, Oregon and Colorado, and found that yield values of the best-performed region were almost 60% better than those in the worst-performed region.

As a matter of fact, PVPP site selection is a complicated multi-criteria decision-making (MCDM) process, because the site is required to be climatically and geographically satisfactory and have the highest generation potentials simultaneously [12]. Hence, decision makers must have access to enough information to assess sites under different criteria, such as sunshine duration, sunshine radiation, soil and transportation [13]. Some researchers have utilized a number of criteria to evaluate solar power plant sites. For example, Tahri et al. [14] used four criteria: location, orography, land use and climate to assess the suitability of locations to carry out the photovoltaic solar energy project, and they found that climate was the most important criterion. Jun et al. [15] constructed an indicator system including natural resources, economic factors, traffic conditions, environmental factors, and social factors to assess seven solar/wind hybrid power stations. Uyan [17] identified environmental and economic factors as the basis to evaluate suitable site for solar farms.

Generally, resource criteria (such as solar energy), economic criteria (such as cost and benefit), and environmental criteria (such as pollutant discharge reduction and land use) are the most used criteria by

* Corresponding author at: School of Economics and Management, Beihang University, Beijing 100191, China.
E-mail address: wenyansong@foxmail.com (W. Song).

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Nomenclature

Abbreviations

AHP analytic hierarchy process
ANP analytic network process
DEMATEL decision-making trial and evaluation laboratory
ELECTRE elimination et choice translating reality
GIS geographic information system
MCDM multi-criteria decision-making
NIS negative ideal solution
PIS positive ideal solution
PT prospect theory
PV photovoltaic
PVPP photovoltaic power plant
TOPSIS technique for order preference by similarity to ideal solution
VPRN variable precision rough number
VIKOR VIšekriterijumsko kompromisno rangiranje

Notations

ζ_j evaluation set of the jth criterion's importance provided by experts
ζ_j^k the kth expert's evaluation for the jth criterion's importance
d number of experts in the decision-making team
g Vague distance of evaluation set
α variable precision
$\underline{Apr}^{\alpha}(\zeta_j^k)$ lower approximation of ζ_j^k
$\overline{Apr}^{\alpha}(\zeta_j^k)$ upper approximation of ζ_j^k
$VPRN^{\alpha}(\zeta_j^k)$ variable precision rough importance of ζ_j^k
ζ_j^{kL} lower limit of $VPRN^{\alpha}(\zeta_j^k)$
ζ_j^{kU} upper limit of $VPRN^{\alpha}(\zeta_j^k)$
p number of elements in $\underline{Apr}^{\alpha}(\zeta_j^k)$
q number of elements in $\overline{Apr}^{\alpha}(\zeta_j^k)$
$IBR^{\alpha}(\zeta_j^k)$ interval of boundary region of ζ_j^k
$\overline{VPRN^{\alpha}(\zeta_j)}$ group rough importance of ζ_j
ζ_j^L and ζ_j^U lower limit and upper limit of group rough importance, respectively
$\widetilde{\zeta}_j^L$ and $\widetilde{\zeta}_j^U$ normalized form of ζ_j^L and ζ_j^U
$\widetilde{\zeta}_j$ thedeterministic value of the group rough importance
$\widetilde{\zeta}_j'$ normalized value of $\widetilde{\zeta}_j$
M^k the kth expert's decision matrix for all PVPP sites with respect to each criterion
z_{ij}^k the kth expert's evaluation for the ith site against the jth criterion
$VPRN^{\alpha}(z_{ij}^k)$ variable precision rough evaluation of z_{ij}^k
z_{ij}^{kL} lower limit of $VPRN^{\alpha}(z_{ij}^k)$
z_{ij}^{kU} upper limit of $VPRN^{\alpha}(z_{ij}^k)$
VPR^{α} variable precision rough group decision-making matrix
$[z_{ij}^{L'}, z_{ij}^{U'}]$ normalized form of $[z_{ij}^L, z_{ij}^U]$
z_j^+ PIS of the criterion ζ_j
z_j^- NIS of the criterion ζ_j
s_{ij}^+ separations of the ith site relative to the jth criterion from the PIS
s_{ij}^- separations of the ith site relative to the jth criterion from the NIS
$v(x)$ value function
σ and ς concave-convex degree of the curves in the areas of gains and losses, respectively
$w^+(\widetilde{\zeta}_j')$ weighting function value of the $\widetilde{\zeta}_j'$ for gains
$w^-(\widetilde{\zeta}_j')$ weighting function value of the $\widetilde{\zeta}_j'$ for losses
δ and θ people's attitude to risk-benefit and risk-loss, respectively
v_i^+ the ith PVPP site's weighted prospect function values for gains
v_i^- the ith PVPP site's weighted prospect function values for losses
c_i closeness coefficient of the ith PVPP site

practitioners and scholars to evaluate the sites of a PVPP. Social criteria are often omitted in the previous researches, which are also important for building PVPP sites. For example, energy policy has a significant influence on construction and operation of energy projects [18]. Many countries (e.g., Germany, France, Spain, China, and Australia, etc.) have announced renewable energy policies to support the growth of energy industry. In this context, policy support must be investigated in the process of PVPP sites selection. Public acceptance is another key social factor to implement energy technologies [19]. For instance, larger PV power plants have visual impact on people, which may hinder the social acceptance of the facilities [20]; The majority of people in possible PVPP sites are mainly ethnic minorities in China and they have different religious belief. Thus, public acceptance should also be considered [12]. In summary, it is necessary to simultaneously take into account criteria of resource, economy, environment and society when evaluate PVPP sites. The evaluation criteria of PVPP sites in the previous studies are systematically summarized in Appendix A.

A number of decision-making techniques have been developed in the previous research works for site selection of solar farms and other energy projects. For example, Tahri et al. [14] applied Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) to evaluate solar farm locations. Chang [21] developed a goal programming model to select appropriate locations for different types of renewable energy facilities. Jun et al. [15] evaluated seven regions of wind/solar hybrid power stations via ELECTRE-II and found the result had better correctness than related research findings. Maleki et al. [22] provided a framework integrating GIS, artificial bee swarm optimization, and simulation to determine the suitable size and location for PV panels. Although the methods above can help investors to select a relatively optimal site to implement energy projects, vague and imprecise information is usually inherent in the decision-making process of site selection. The methods mentioned above cannot deal with the vagueness or ambiguity in uncertain environments because they use crisp values to represent vague judgments of decision makers.

To manipulate the vagueness and subjectivity of judgments, fuzzy set theory is frequently used. It allows decision makers to incorporate incomplete information and unquantifiable information into the decision model [23]. Scholars often integrate this theory into MCDM approaches to manipulate imprecise information during sites evaluations. For instance, Lee et al. [24] proposed a hybrid fuzzy MCDM approach incorporating interpretive structural modeling, fuzzy analytic network process (ANP) and VIšekriterijumsko kompromisno rangiranje (VIKOR) to select PV solar plant locations. Sánchez-Lozano [26] used fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method to evaluate the locations for the installation of solar thermoelectric power plants. Zoghi et al. [29] optimized solar site selection through fuzzy logic, weighted linear combination, and MCDM process. Noorollahi et al. [30] applied fuzzy AHP (FAHP) process to determine the criteria's relative weights in land suitability analysis for solar farms. Wu et al. [31] utilized ELECTRE-III to select offshore wind farm sites in the intuitionistic fuzzy environment. Fuzzy based approaches can quantify decision makers' vagueness so as to improve