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Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective

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HIGHLIGHTS

- The EVCS site selection was studied from sustainability perspective.
- Fuzzy TOPSIS method was employed to select the optimal EVCS site.
- Evaluation index system for EVCS site selection was built.
- The optimal EVCS site was selected due to its highest closeness coefficient.
- Sensitive analysis was performed to verify the robustness of decision result.

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ABSTRACT

Selecting the most sustainable site plays an important role in the life cycle of electric vehicle charging station (EVCS), which needs to consider some conflicting criteria. Different from the previous studies which mostly utilize programming (optimization) models, this paper employed a multi-criteria decision-making (MCDM) method to consider some subjective but important criteria for EVCS site selection. To reflect the ambiguity and vagueness due to the subjective judgments of decision makers, fuzzy TOPSIS method was applied to select the optimal EVCS site. Based on academic literatures, feasibility research reports and expert opinions in different fields, the evaluation index system for EVCS site selection was built from sustainability perspective, which consists of environmental, economic and social criteria associated with a total of 11 sub-criteria. Then, the criteria performances of different alternatives and criteria weights were judged by five groups of expert panels in the fields of environment, economy, society, electric power system and transportation system. Finally, the EVCS site alternatives were ranked by employing fuzzy TOPSIS method. The result shows EVCS site A2 located at Changping district in Beijing obtains the highest ranking score and should be selected as the optimal site. Meanwhile, the environmental and social criteria are paid more attentions from decision makers than economic criteria. The sensitivity analysis results indicate the alternative A2 always secures its top ranking no matter how sub-criteria weights change. It is effective and robust to apply fuzzy TOPSIS method into EVCS site selection. This paper provides a new research perspective for site selection and also extends the application domains of fuzzy TOPSIS method.

Abbreviations: CO_2, carbon dioxide; EVCS, electric vehicle charging station; EV, electric vehicle; GHG, greenhouse gas; MCDM, Multiple-Criteria Decision-Making; TOPSIS, technique for order of preference by similarity to ideal solution; NOx, nitrogen oxide; SOx, sulfur oxides; CO, carbon monoxide; DC, direct current; SoC, state of charge; PEVs, plug-in electric vehicles; PSO, particle swarm optimization; CCSs, centralized charging stations; G2V, grid-to-vehicle; V2G, vehicle-to-grid; V2V, vehicle-to-vehicle; MILP, mixed integer linear programming; MODM, multi-objective decision making; GA, genetic algorithm; TFN, triangular fuzzy number; ICEV, internal combustion engine vehicle; CH_4, methane; PM_{10}, particulate matter with particle size below 10 μm; $PM_{2.5}$, particulate matter with particle size below 2.5 μm; CC, closeness coefficient; AHP, analytical hierarchy process; VIKOR, **VI**šekriterijumsko **KO**mpromisno **R**angiranje' (multi-criteria optimization and compromise ranking); ELECTRE, **EL**imination **E**t **C**hoix **T**raduisant la **RE**alité (elimination and choice expressing reality).

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1. Introduction

With the world economy development and natural resources depletion, energy crisis and ecological environment deterioration have become severe issues for the sustainable development of today's world [1,2]. Therefore, many countries have proposed the corresponding routes and strategies for energy utilization. China has become the largest CO_2 emitter in the world, and the carbon emission from transportation sector accounts for about 6% [3]. The growth rates of energy consumption and carbon emission in transportation sector are both higher than the national average levels, which have been stimulated by the urbanization development and increasing demand on automobiles in the past few years [4]. Electric vehicle (EV), as a kind of new environmentally–friendly means of transportation, plays a vital role in the urban atmospheric pollution emission reduction and low-carbon transportation development [5]. With the continuous improvement of battery capacity and economies, electric vehicle has become the main development tendency of new energy automobiles. Meanwhile, if taking the appropriate charging mode, electric vehicle can shift the power peak load, provide spinning reserve and improve the penetration of renewable energy power. Therefore, the electric vehicle can promote the safe, stable and economic operation of electric power grid to some extent [6]. Currently, the electric vehicle has drawn more and more attentions from governments and general public. Developing electric vehicle is an effective way to tackle the issues related to the fossil resource depletion and environmental pollution worsening, which can also promote the urban sustainable development [7,8].

As the energy provider of electric vehicle, electric vehicle charging station (EVCS) is the foundation of electric vehicle industry development. Efficient, convenient and economic EVCS can enhance the willingness to buy of consumers and promote the industry development. As the preliminary work of EVCS construction, the EVCS site selection is quite important in the whole life cycle, which has significant impacts on the service quality and operational efficiency of EVCS. Therefore, it is necessary to employ proper method to determine the optimal EVCS site [9,10].

'Sustainability' refers to the long-term development which includes three pillars/dimensions: economic growth, social development and environmental protection [11,12]. In this paper, the EVCS site selection will be performed from sustainability perspective. For economic dimension, the cost and benefit implication of EVCS such as construction cost, annual operation and maintenance cost and investment pay-back period are incorporated into the decision-making process. For social dimension, some factors such as the harmonization of EVCS with the development planning of urban road network and power grid, traffic convenience, service capability and impact on people's lives are considered. For environmental dimension, the environmental impacts induced by EVCS such as vegetation and water destruction, waste discharge, GHG emission reduction and fine particulate matter emission reduction are included in order to evaluate the positive and negative impacts related to EVCS.

Considering that the EVCS site selection includes economic, social and environmental aspects, a Multiple-Criteria Decision-Making (MCDM) technique is employed to select the optimal EVCS site from all alternatives under consideration of various conflicting criteria in this paper. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a compensatory aggregation MCDM method which has the advantages of good computational efficiency and ability to measure the relative performance for each alternative in a simple mathematical form, so it has been applied in many fields [13,14]. However, in real world, due to the ambiguity as well as intangibility arising from human qualitative judgments and the vagueness as well as uncertainty due to the information deficiency, some criteria cannot be measured by crisp value, but can only by fuzzy value [15], such as the harmonization of EVCS with the development planning of urban road network and power grid. Fuzzy set theory, proposed by Zadeh, can effectively tackle this kind of issue [16]. Therefore, fuzzy TOPSIS method which combines the fuzzy set theory and traditional TOPSIS method was proposed [17]. In fuzzy TOPSIS method, the triangular (trapezoid) fuzzy number is used to represent the criteria with the characteristic of fuzziness. In this paper, the fuzzy TOPSIS method will be employed to select the optimal EVCS site.

The rest of this paper is organized as follows: Section 2 reviews the literatures related to EVCS in terms of technology and economy and EVCS site determination, and then defines the main contributions of this paper; In Section 3, the basic theories of fuzzy set and fuzzy TOPSIS method are elaborated; The evaluation index system for EVCS site selection is built in Section 4; Section 5 performs the EVCS site selection by employing the fuzzy TOPSIS method; Result analysis and sensitivity analysis are carried out to check the rationality and robustness of obtained result in Section 6; In the last section (Section 7), the conclusion is provided.

2. Literature review

The construction of electric vehicle charging station is important in its whole life cycle. The appropriate site selection and capacity determination on EVCS can benefit the multiple stakeholders and promote the sustainable development of whole industry. Over the past few years, some studies related to EVCS in terms of technology and economy have been conducted. Nansai et al. [18] performed the life-cycle analysis on EVCS in three phases, namely the production, transportation and installation of EV charging equipment, and then conducted the comparison between EV and gasoline vehicle in terms of CO_2, NOx, SOx and CO emissions. Li et al. [19] studied the energy management and control of EVCS in a dynamic price framework, and developed a real-time simulation system for evaluating how EVCS can meet charging and discharging requirements for G2V, V2G, and V2V. Capasso and Veneri [20] proposed a DC fast charging architecture for full electric and plug in hybrid vehicles with the integration of renewable energy sources and fleets of road electric/hybrid vehicles. Fan et al. [21] studied the impacts of limiting EVs' requested full state of charge (SoC) on total charged energy and revenue of fast EVCS. Ding et al. [22] proposed the consideration of energy storage system as a potential supplement of electric bus fast charging station, and employed mixed integer nonlinear programming to value the energy storage system in electric bus fast charging station. Wang et al. [23] used three-phase uncontrolled rectification chargers to study the harmonic amplification of EVCS. Rivera et al. [24] proposed a novel architecture for PEVs dc charging station by using a grid-tied neutral point clamped converter. Lee et al. [25] studied the price competition among EVCSs with renewable power generators by employing game theory with consideration of relevant physical constraints.

Currently, there are some studies focusing on placing and sizing EVCS. Antunes et al. [9] employed a maximal covering model to study the location of EVCS in Portugal and to define the number and capacity of EVCS. Khalkhali et al. [26] employed data envelopment analysis to determine the optimal size and location of plug-in hybrid EVCS by maximizing the benefit of distribution system manager. Wirges et al. [27] proposed a dynamic spatial model for allocating the need for EVCS in Germany, and also gave several scenarios for the charging infrastructure development until 2020. Liu [28] estimated the charging demand of early electric vehicle market in Beijing, and proposed an assignment model for different