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Development of a Bayesian network model for optimal site selection of electric vehicle charging station

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ABSTRACT

Fast charging sites play a crucial role for public acceptance of electric vehicle (EV). Selection of the most sustainable site positively contributes to the life cycle of electric vehicle charging station (EVCS), which requires considering some conflicting criteria. Previous researches mainly focused on utilizing optimization models to deal with EVCS site selection that only accounts for quantitative factors, while this paper proposes a Bayesian Network (BN) model that considers not only quantitative factors but also qualitative (subjective) ones. Based on academic literature and expert judgments, the assessment index for EVCS site selection was mainly made from sustainability point of view, which contains of economic, environmental, and social criteria with a total of eleven sub-criteria. BNs are powerful tools for handling risk assessment and decision making under uncertainty. The developed BN model is validated through sensitivity analysis approach. Finally, different propagation analyses have been performed to make special types of reasoning. This paper provides a new research perspective by considering uncertainty, qualitative and quantitative factors into the site selection assessment, and presents the mainstream penetration of BN as a powerful decision making tool in the context of electrical energy management.

1. Introduction

With the world economy development and natural resources depletion, energy crisis and ecological environment deterioration have become critical issues for the sustainable development of today's world [1]. Hence, countries across the globe have employed different strategies to efficiently utilize energy. According to the report released by Environmental Performance Index [2], Iran has the highest share of CO_2 emissions in the Middle East region and listed the first ten countries in the world with approximately 655 million metric tons of CO_2 emitted from consumption of energy. The growth rate of energy utilization and carbon dioxide emission in transportation systems are both higher than the national average level, which forced Iran's government to seek more efficient means in the public and private transportation sector [3].

Electric vehicle (EV) has received a great deal of attentions as an alternative for internal combustion engine vehicles (ICEV) due to its economic affordability and environmental significance. Both government and Tehran Municipality are supporting ongoing researches on various aspects of EV application to provide profound insight for policy-making on electro-mobility [4]. EV is a new environmentally friendly means of transportation which plays a significant role on pollution emission reduction. With continuous improvement of battery technology, EV has become the center of tendency for new energy automobiles. Development of EV is an effective way to tackle the concerns related to fossil resource depletion and environmental pollution deterioration, which can also promote the urban sustainable development [5,1].

Electric vehicle charging station (EVCS) as the energy provider of electric vehicle is the foundation of industry development for electric vehicle. Efficient, appropriate and economic EVCS can raise the willingness of customers to buy and promote the industry development. The site selection of EVCS is not only important to the whole life cycle of EVCS but also has significant impacts on the service quality and operational efficiency of EVCS. Hence, optimal EVCS site must be determined using proper decision making method.

Sustainability in the scope of energy management aims to meet the needs of present without compromising the ability of future generations to meet their energy demands. This can be yielded by developing renewable sources, producing cleaner and more-efficient technologies and finally utilizing more efficiently and with greater conservation. Sustainability in the context of renewable energy management consists

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of three dimensions: economic development, social development and environmental protection [6]. The focus of this paper is to investigate the EVCS site selection from a sustainability perspective. The contributing factors to the economic dimension, the first dimension of sustainability are costs associated with EVCS including cost of construction, maintenance and operating cost. For social dimension, some factors including service level capability and impact on people's lives, traffic convenience, population density, location's safety and security are taken into account. For environmental dimension, the environmental factors induced by EVCS such as water destruction, waste discharge, and greenhouse gas (GHG) emission reduction are considered.

In this paper, a Bayesian Network (BN) is developed to deal with the selection of optimal EVCS site based on considering a set of conflicting criteria. BN is a powerful technology for handling risk assessment, uncertainty and decision making. BNs can describe causes and effects using a graphical framework that provides for the rigorous quantification of risk that combines different type of variables including continuous, Boolean (*e.g.*, true/false), constant and ordinal (*e.g.*, low/medium/high). One that distinguishes BNs from other multi-criteria decision making approaches such as Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is the ability of modeling both qualitative and quantitative variables and powerful feature of scenario analysis called propagation analysis or belief propagation. During the last decade, researchers have incorporated the BNs tool in the different domain applications such as risk and safety assessment [7,8,13], fault diagnosis [12,14], traffic management [15], resilience modeling of infrastructures [9–11, etc. In this paper a BN model is developed to select the optimal EVCS site location.

The remainder of this paper is structured as follows: Section 2 reviews the literature related to existing approaches for selecting EVCS site. Section 3 briefly describes BN tool and its advantages. Section 4 described the evaluation criteria for EVCS site selection. Section 5 explains the BN based framework. Section 6 discusses the developed BN model for evaluating EVCS site alternatives. Sensitivity analysis and propagation analysis of BN model are discussed in Sections 7 and 8, respectively. Finally the conclusion is given in Section 9.

2. Literature review

One of the primary and long-term decisions in the context of EV management is where to locate EVCS site? Selecting the sustainable site plays a key role in the life cycle of EVCS. Over the last decade, many research efforts have been devoted to the economic and technology aspects of EVCS. Nansai et al. [16] analyzed the life-cycle of EVCS in terms of transportation, installation and production and advantages of EV are compared to gasoline vehicle (GV) in terms of CO_2, NO_x, and CO emissions. Wang et al. [17] assessed energy consumption of EVs in real-world driving conditions and also quantified the impact of driving patterns on energy use of EVs. Saxena et al. [18] showed that normal daily travel of 85–89% of drivers in the United States can be met with EVs charging with standard 120 V wall outlets at home only. Donateo et al. [19] evaluated the impact of greenhouse (CO_2) and air pollutants (NO_x, CO, and HC) from EVs in Italian cities. Yuan et al. [20] analyzed the energy consumption distribution of battery in EVs. The authors determined the impact of driving patterns on battery electric vehicle (BEV) model. Dong et al. [21] used activity-based assessment method to evaluate BEV feasibility for the heterogeneous traveling population. They applied Genetic algorithm (GA) to find optimal locations for locating public charging stations. Meng and Kai [22] applied game theory based on Nash equilibrium to deal with site location problem. You and Hsieh [23] proposed a mixed-integer programming model which aims to maximize the number of people who can complete round-trip itineraries. The proposed optimization model was then solved by using a hybrid genetic algorithm. Shahraki et al. [24] introduced an optimization model for selection of electric public charging stations which aims to maximize the amount of vehicle-miles-traveled being electrified. Their findings indicate that when the total number of charging stations increases, the locations of the optimal stations expand outward from the inner city. Yao et al. [25] proposed a multi-objective collaborative planning strategy for locating EVCS. Their proposed mathematical model aims to simultaneously minimize the overall annual cost of investment and energy losses and maximize the annual traffic flow captured by charging stations. Baouche et al. [26] introduced an integer linear programming model for site selection of EVCS. Chen and Hua [27] established an optimization model based on set covering model for site location of EVCS. The objective function of their proposed model is to minimize the transformation cost. Lam et al. [28] proposed a mixed integer programming model for placement of vehicle charging stations. Andrews et al. [29] proposed an integer linear programming model to determine optimal site locations. Their proposed optimization model aims to minimize the total distance traveled by all vehicles to access the selected charging stations. Guo and Zhao [1] developed a fuzzy TOPSIS for evaluating site selection alternatives of EVCS. Xu et al. [30] established a simple optimization model which selects the optimal site locations based on maximizing utility score of locations. Chung et al. [31] developed a multi-period optimization model for charging station planning of EV based on flow-refueling location model. The authors validated their proposed model through real traffic flow data of Korean Expressway network. Sadeghi-Barzani et al. [4] proposed a mixed integer nonlinear programming model for placing and sizing of EVCS. The station development cost, electric grid, and EV energy loss are taken into account in their proposed model. The authors finally assessed the impact of grid reliability on charging station placement.

After analyzing the literature, it can be concluded that the majority of existing researches related to the site selection of EVCS is concentrated on optimization approaches such as linear/nonlinear programming, stochastic programming, mixed-integer programming. In most cases, meta-heuristic algorithms such as GA and PSO were applied to tackle the complexity of optimization models. Generally speaking, there are two major critiques with optimization approaches. First, although the aforementioned optimization models are significantly remarkable but less likely can be implemented in practice due to its complexity of modeling real-world problems. Second, optimization models can only account for quantitative variables such as construction costs of charging station, electric grid loss, EV energy loss, and so on but are not capable of modeling important qualitative variables such as ecological environment (e.g., waste discharge), etc. In this paper, we develop a BN for placing optimal site of EVCS. The main contributions of this paper are as follows:

- It provides a BN model that assesses the site locations of EVCS with a focus on sustainability perspective by considering both qualitative and quantitative factors.
- BN is a powerful tool that has been applied for decision making under uncertainty in various disciplines. To the best of our knowledge, this is the first attempt to assess alternatives of site locations of EVCS which aim to present mainstream penetration of BN tool in the context of renewable energy management.
- Sensitivity analysis has been performed not only to validate the model but also identify the most impactful factors into the site selection problem. We also implemented propagation analysis which highlights how variability of a factor (e.g., number of EV get served per day) may change the optimal site location.

3. Bayesian network (BN)

BNs are structured based on Bayes' theorem, capable of updating the prior probability of some unknown variable when some evidence describing that variable exists. BNs can graphically represent such problems where uncertain variables are represented as vertices (nodes), with an edge representing the causal relationship between two vertices,