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A New Fuzzy Decision-Making Model for Enhancing Electric Vehicle Charging Infrastructure

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ABSTRACT

Electric vehicles are very important for the country's economy. Thanks to the use of these vehicles, both environmental and economic benefits can occur for countries. However, there are some problems that prevent the development of electric vehicles. The inadequacy of charging stations is one of the most important problems in this process. This problem prevents the preference of electric vehicles. Therefore, a comprehensive analysis is required to solve this problem. Accordingly, this study aims to determine strategy suggestions that will increase the effectiveness of charging stations for electric vehicles. To achieve this goal, a new decision-making model is proposed in this study. In this model, multi-criteria decision-making techniques are integrated with fuzzy logic. The findings indicate that technological improvements play the most crucial role to increase the effectiveness of these investments. Similarly, increasing charging stations has also a positive influence for this situation.

1. Introduction

Electric vehicle charging infrastructure investments are very important for the country's economy [1]. These projects are necessary to reduce environmental pollution in the country. Thanks to these investments, carbon emissions can be reduced. These projects are also necessary for the economic development of countries [2]. Thanks to these investments, new job opportunities are created in the country. This situation is also very necessary to solve the unemployment problem in the country. In addition, with the increase in these investments, the trade volume of many companies in the supply chain increases [3]. In summary, electric vehicle charging infrastructure investments have a great impact both environmentally and economically. Therefore, the use of electric vehicles should be widespread. On the other hand, there are some disadvantages in electric vehicle investments. For example, these projects are not preferred by many customers because there is not enough charging infrastructure [4]. Therefore, this problem needs to be solved to increase customer satisfaction to

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ensure customer satisfaction. To achieve this goal, an effective charging infrastructure is essential for the creation of sustainable transportation systems.

To increase the charging infrastructure investments of electric vehicles, improvements should be made for some variables [5]. For example, the development of the technological infrastructure of enterprises is of critical importance in this process. Technological developments have a positive effect on the performance of these projects in many ways. This is primarily necessary to increase the charging speed. By increasing the charging speed, cars will be able to charge much faster. This situation also significantly supports the increase in customer satisfaction. Developing technologies also help to increase battery capacity [6]. The development of electric vehicle battery technologies directly affects the demand for charging infrastructure. If the battery capacity is high, it can reduce the charging frequency. With the development of the technological infrastructure, it is possible to ensure the integration of the burner. For example, with advanced technologies, it is possible to implement the smart grid system much more effectively [7]. This situation also contributes greatly to the improvement of the performance of electric vehicle investments.

Financial issues are also very necessary to increase the charging infrastructure investments of electric vehicles [8]. If the financial performance of the investments is not high, investors do not show interest in these projects. This puts the long-term sustainability of the projects at risk. In this context, financial performance must be high for these investments to be developed. Therefore, the installation and operating costs of charging stations must be reduced [9]. Technological development is very important in this process. Thanks to new technologies, it is possible to have lower costs. This situation also allows businesses to increase their competitive advantage. Because of this issue, some actions must be taken to reduce the costs of the projects. A comprehensive feasibility analysis contributes significantly to achieving this goal. Thanks to this analysis, it is possible to create a more successful cash balance for businesses. This situation also contributes to reducing the possibility of businesses experiencing liquidity risk. On the other hand, state supports also support the reduction of the costs of these projects. Incentives such as tax reductions contribute significantly to the reduction of project costs [10].

It is necessary for the effectiveness of charging station investments in geographical conditions for electric vehicles [11]. In this context, charging stations should be established in different regions. Otherwise, some people living in the country will not be able to reach charging stations. In this case, these people will not use electric vehicles. As can be seen, the use of electric vehicles will decrease significantly as a result. To solve this problem, charging stations should be established in different regions within the country [12]. In this way, the problem of charging electric vehicles can be significantly minimized. In this context, the necessary regulations should contribute to the solution of this problem. In this context, electric vehicle manufacturers should be obliged to maintain charging stations in certain regions within the country. This situation should be made a legal rule with regulations throughout the country. Businesses that do not want to experience a financial penalty in a legal sense will open charging stations in different geographical regions [13]. In this case, it seriously supports the solution of the problem in question.

This study aims to determine strategy suggestions that will increase the effectiveness of charging stations for electric vehicles. Electric vehicles are of great importance for the country's economy. However, due to some economic issues, the development of these projects is quite difficult. Problems related to charging stations are also an important example of these problems. Therefore, minimizing these problems related to charging stations will also contribute to the development of electric vehicle projects. To achieve this goal, a new decision-making model is proposed in this study. In this model, multi-criteria decision-making techniques are integrated with fuzzy logic.

This manuscript has 4 different sections. The following part gives information about the proposed model. The third part is related to the analysis results. The final part demonstrates the main conclusion.

2. Methodology

Fuzzy sets are mathematical theory developed for the measurement of uncertainty [14]. Fuzzy set theory, which provides the ability to calculate with words, is developed to analyze the types of uncertainty with different set definitions. Picture fuzzy sets are a variant of fuzzy set theory. According to the definition of this set, the sum of degrees of the positive membership, negative membership and neutral membership of an element lies between 0 and 1. This ensures that uncertainty is analyzed better, and the results are closer to reality [15].

The DEMATEL method is a multi-criteria decision-making technique that determines the priority order by analyzing the actions between the factors affecting a target [16]. The DEMATEL method first begins with experts evaluating the impact of the criteria on each other. With these evaluations, the initial decision matrix is created. This matrix is then normalized [1]7. In the normalization process, the maximum value of sums of the rows and columns of the initial decision matrix is determined, and the elements of the initial decision matrix are divided by this value. Then the total relation matrix is calculated. And the row and column totals are calculated in this matrix [18]. Using these two total values, the importance priorities of the criteria are determined.

3. Results

The criteria and codes selected from the literature for analysis are given in Table 1.

Table 1
Criteria Sets

Definition	Code
Technological improvements [19]	TECHIMP
Charing facilities [20]	CHRFAC
Financial issues [21]	FINISS
Customer expectations [22]	CUSEXP

The criteria are evaluated by people who have proven expertise in the field. The opinions of three experts are given in Table 2.

Table 2
The Opinions

Expert1	TECHIMP	CHRFAC	FINISS	CUSEXP
TECHIMP	-	7	6	5
CHRFAC	5	-	5	6
FINISS	5	6	-	4
CUSEXP	4	5	2	-
Expert2	TECHIMP	CHRFAC	FINISS	CUSEXP
TECHIMP	-	5	6	4
CHRFAC	5	-	4	6
FINISS	4	3	-	5
CUSEXP	4	4	4	-
Expert3	TECHIMP	CHRFAC	FINISS	CUSEXP
TECHIMP	-	7	5	6
CHRFAC	5	-	4	5
FINISS	3	3	-	4
CUSEXP	5	5	6	-

The opinions are transformed into picture fuzzy numbers. Then, the initial decision matrix is constructed by taking the average of the picture fuzzy numbers. The initial decision matrix is shown in Table 3.

Table 3
The Initial Decision Matrix

Crit.	TECHIMP			CHRFAC			FINISS			CUSEXP		
TECHIMP	0.000	0.000	0.000	0.841	0.000	0.091	0.708	0.000	0.144	0.632	0.000	0.229
CHRFAC	0.600	0.000	0.300	0.000	0.000	0.000	0.536	0.000	0.363	0.708	0.000	0.144
FINISS	0.481	0.000	0.416	0.503	0.000	0.330	0.000	0.000	0.000	0.536	0.000	0.363
CUSEXP	0.536	0.000	0.363	0.569	0.000	0.330	0.546	0.063	0.288	0.000	0.000	0.000

The elements of the initial decision matrix are defuzzified and then normalized. The normalized values are displayed in Table 4.

Table 4
The Normalized Values

	TECHIMP	CHRFAC	FINISS	CUSEXP
TECHIMP	0.000	0.437	0.328	0.235
CHRFAC	0.175	0.000	0.100	0.328
FINISS	0.038	0.101	0.000	0.100
CUSEXP	0.100	0.139	0.113	0.000

In the next step, the total relation matrix is calculated. The total relation matrix is illustrated in Table 5.

Table 5
The Total Relation Matrix

	TECHIMP	CHRFAC	FINISS	CUSEXP
TECHIMP	0.187	0.646	0.516	0.542
CHRFAC	0.271	0.213	0.266	0.489
FINISS	0.089	0.172	0.067	0.185
CUSEXP	0.167	0.253	0.210	0.143

Then, the row and column sums of the total relation matrix are calculated. Finally, the weights of the criteria are obtained. The criteria weights are shared in Table 6.

Table 6
The Weights of the Criteria

Criteria	Weights
TECHIMP	0.309
CHRFAC	0.273
FINISS	0.180
CUSEXP	0.239

According to Table 6, the most important criteria are technological improvements and Charing facilities.

4. Conclusions

Electric vehicle charging infrastructure investments are very important for the country's economy. These projects are necessary to reduce environmental pollution in the country. Owing to these investments, new job opportunities are created in the country. This situation is also very necessary to solve the unemployment problem in the country. However, due to some economic issues, the development of these projects is quite difficult. Problems related to charging stations are also an important example of these problems. Therefore, minimizing these problems related to charging stations will also contribute to the development of electric vehicle projects. This study aims to determine strategy suggestions that will increase the effectiveness of charging stations for electric vehicles. To achieve this goal, a new decision-making model is proposed in this study. In this model, multi-criteria decision-making techniques are integrated with fuzzy logic. The findings indicate that technological improvements play the most crucial role to increase the effectiveness of these investments. Similarly, increasing charging stations has also a positive influence for this situation.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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