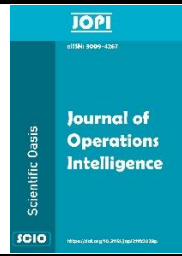




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## Development of Optimal Investment Strategies for Electric Vehicle Charging Stations with a Novel Decision-Making Technique

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### ABSTRACT

Electric vehicles (EVs) have become widespread, especially in recent years. However, the infrastructure required for charging these vehicles is inadequate, and the necessary investment strategies need to be determined for the effective establishment of this infrastructure. Electric vehicle charging stations are a fundamental component of sustainable transportation systems. In parallel with the increasing EV demand, determining appropriate investment strategies to support the installation of these stations is a critical need. This study aims to identify the optimal investment strategies for the effective establishment of EV charging stations, addressing the growing demand for sustainable and environmentally friendly transportation solutions. With the increasing adoption of electric vehicles, the development of an efficient EV charging infrastructure becomes critical. Thus, it is intended to determine the most suitable strategies for building efficient charging station infrastructures. The motivation for this research arises from the necessity to strengthen the existing charging infrastructure in response to the rising number of electric vehicles and the need for sustainable transport solutions. Electric vehicle charging stations are vital components of sustainable mobility, making it essential to evaluate the investment strategies that will enable their successful establishment and operation. To achieve the study's goal, a detailed analysis has been conducted using the decision-making trial and evaluation laboratory (DEMATEL) technique. The findings from this analysis emphasize that technological improvement is the most crucial factor in enhancing the performance of EV charging infrastructure projects. Technological advancements such as faster charging technologies, greater energy efficiency, and better user interfaces are paramount to ensuring the success of these projects. In addition to technological improvements, financial performance and legal effectiveness also play significant roles in the efficient establishment of EV charging stations. These factors directly impact the feasibility and long-term sustainability of the projects. On the other hand, customer expectations, although important, are found to have the least weight in this regard. In conclusion, this study underscores the importance of focusing on technological advancements, alongside financial and legal factors, to effectively drive the establishment of these stations.

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## 1. Introduction

The automotive sector triggers many sectors and has an important place for national economies as it provides production in other sub-industry parts supply. It feeds many sectors such as plastic, glass, rubber, metal and petrochemical products used in automobile production and creates serious employment, and raw material sales and communication services are provided to the automotive sector from many sectors [1]. In addition, the transportation of many products is done for the automotive sector. Therefore, the automotive sector is in a position to feed and support other sectors. In addition to automotive factories, the investments made by many supplier manufacturers are of great importance for the national economy in terms of employment and export. In addition to production, it has ensured the increase of industrialization in terms of maintenance and repair, employment in industrial branches and the development of production techniques [2].

Today, the rapid and significant technological developments in the automotive sector have caused manufacturers to increase their R&D activities and have caused them to allocate high budgets for R&D globally. In addition, the fact that everything is on a digital platform increases the risk of cybersecurity and causes a lot of private information to be stored on this platform, and cybersecurity poses a risk for the automotive sector. Another challenge in the automotive sector is the laws enacted by countries [3]. Carbon monoxide, which occurs during vehicle use and is released into nature, is seen as a serious threat to global warming, and the laws enacted to minimize this cause manufacturers to conduct different R&D studies, produce more parts in production, and encounter higher costs. For example, Euro 6 engines that meet European Emission Standards are currently being produced, and manufacturers have made different technological developments to minimize the toxic gases released by these engines into the environment and have experienced increases in production costs because they have to comply with the laws enacted by the states. This is one of the challenges faced by the automotive sector [4]. In addition to the challenges experienced by the sector, there are also opportunities. Electric vehicles are one of the important opportunities in the sector. Electric vehicles do not consume fossil fuels, thus reducing the release of toxic gases into the environment and the countries' fossil fuel consumption and needs. It also enables electric vehicle manufacturing companies to reach a global dimension by selling outside their own countries [5].

In the rapidly developing automotive sector, new technologies are causing different trends to emerge. Electric cars can be given as an example in the light of today's developing technology. Fully electric or hybrid vehicles have begun to be preferred by consumers and have begun to reach significant sales figures with their developing technologies. In addition, manufacturers who focus on electric cars and conduct R&D studies in this field have begun to go global by going beyond their countries [6]. In the automotive sector, widespread and developing digitalization on vehicles, autonomous driving, features that increase the comfort of users and passengers in the vehicle have increased expectations in the sector and have led to the formation of new trends. Features such as remote connection with the vehicle, lane tracking assistant, automatic parking, automatic collision prevention, pedestrian safety, etc. have increased driving comfort and safety and have become a preference for consumers [7]. In addition, consumers' awareness of global warming and climate change has increased the tendency towards electric and hybrid vehicles. When security and environmental factors are taken into consideration, environmentally friendly and highly secure vehicles have begun to be preferred today [8].

Electric vehicle technologies have become one of the most important research and development areas of our time. The environmental impacts of internal combustion engine vehicles and the limited resources of fossil fuels are the main factors encouraging the widespread use of electric vehicles. In this context, components such as energy storage systems, charging infrastructures and battery management systems of electric vehicles have become important research topics in both technical

and economic terms [9]. Electric vehicles are divided into classes according to their operating structure and charging methods. Electric vehicle technology covers transportation vehicles that receive power from electrical energy. This concept, which is also encountered as electromobility, includes bicycles, scooters, light and small vehicles. Electric vehicle technologies are divided into three categories: hybrid, 100% electric and fuel cell. Hybrid cars are divided into two groups: classic hybrid vehicles and plug-in hybrid vehicles [10].

In classic hybrid vehicles, the high-voltage lithium-ion battery stores the energy needed for the electric motor. Some of the energy lost during deceleration is regained through recycling and stored in the lithium-ion battery. When a hybrid vehicle is started, the electric system is first activated, and the vehicle's operation and take-off are provided by the electric motor. The highest fuel consumption in automobiles is experienced during take-off. Since the first movement in hybrid automobiles is provided by the electric motor, the high fuel consumption experienced during take-off is prevented and the consumer saves money. After a certain speed, the internal combustion engine is activated, and the electric motor provides support [11]. During deceleration, the gasoline engine is deactivated, and the lithium-ion battery can charge itself thanks to braking. Plug-in hybrid vehicles have a large-volume fuel tank as well as a high-capacity battery. The battery can be charged externally with a cable. Thanks to its high battery capacity, it can travel longer distances with the electric motor. When the fuel runs out, it can continue the road by getting its power from the battery. 100% electric vehicles are vehicles that operate entirely on electricity, do not have a fuel tank and have a high-capacity battery. They can be charged with a cable [12].

The rotor in the electric motor provides movement and transmits it to the tires. To reach high power, it transmits the power to the tires as it is without waiting for any rotation. They are silent, comfortable, low-cost and extremely environmentally friendly vehicles because they do not emit carbon monoxide into the environment [13]. Fuel cell vehicles play an important role in environmentally friendly energy production and use. These vehicles produce electrical energy through the electrochemical reactions of hydrogen, and harmless by-products such as water vapor emerge during this process [14]. The working principle of fuel cells basically involves hydrogen and oxygen coming together to produce electric current. In this context, understanding how fuel cell vehicles work is of critical importance in terms of both technological developments and environmental sustainability. The fuel cell engine generates energy by transmitting the electricity it produces as a result of the contact of oxygen and hydrogen to the battery [15].

Energy projects are known for their high initial costs and long payback periods. Therefore, the problem of finding financing is a significant obstacle, especially for large-scale energy projects. Although renewable energy sources have higher initial costs compared to fossil fuels, they attract investors' attention because they offer low operating costs in the long term. However, the need to find sufficient financing to start such projects continues [16]. Energy production is a major concern in terms of environmental impacts. The combustion of fossil fuels increases global warming by releasing carbon dioxide and other greenhouse gases into the atmosphere. Although renewable energy sources aim to reduce environmental impacts, the environmental costs of some types are still a matter of debate [17]. With the acceleration of production and consumption for the sustainability of life, a wide transportation network, etc., and new technological developments, the need for energy has also increased at the same rate [18]. Due to the widespread use of fossil fuels, carbon emissions into nature are high, and as a result, problems such as global warming and climate change occur. The energy sector is a field that requires high technical knowledge and expertise [19]. The problem of qualified personnel emerges in the rapidly changing and developing energy sector. However, when the curricula of faculties and vocational schools are not updated in parallel with new technological developments, this may cause graduates not to receive an education that will meet the needs of the

sector. Rapidly changing technologies require those working in the sector to have competence, up-to-date information and the necessary skills. If professional competence is not present, the problem of qualified personnel arises [20].

This study aims to determine the optimal investment strategies required for the effective establishment of electric vehicle charging stations. The research question of this study can be as follows: "Which optimal investment strategies should be determined for the effective establishment of electric vehicle charging stations?". This question determines the main purpose and focus of the study. The study focuses on determining the most appropriate investment strategies for the efficient establishment of electric vehicle charging stations. The main motivation for this study is the necessity of strengthening the infrastructure of electric vehicle charging stations along with the increasing prevalence of electric vehicles and the increasing demand for environmentally friendly transportation options. Since electric vehicle charging stations are an important part of sustainable transportation, determining the optimal investment strategies for the efficient and effective establishment of these infrastructures is of critical importance. To achieve this goal, an analysis is carried out using the DEMATEL technique.

## **2. Methodology**

DEMATEL (Decision-Making Trial and Evaluation Laboratory) is a multi-criteria decision-making technique used to determine relationships in complex systems [21]. DEMATEL is used to understand a complex system or a large number of factors. Within this system, it analyzes the effect of each factor on other factors [22]. DEMATEL tries to determine whether the relationships between factors are of the cause-effect type. The DEMATEL technique can be applied using expert opinions (qualitative data) and numerical data [23]. Experts usually express the effects between factors using a rating between 0 and 4. This indicates how effective each factor is on other factors [24].

The application stages of the DEMATEL technique are as follows.

- 1- First, the factors to be analyzed are determined.
- 2- The interactions between each factor are rated by experts.
- 3- Direct effect matrices between factors are created with the data obtained from expert opinions.
- 4- The total effect matrix is derived from the direct effect matrix.
- 5- With the obtained data, it is determined whether each factor is a causal or effect factor [25].

## **3. Results**

### *3.1 Definition of the Criteria*

The most important part of electric vehicles is the battery, which is the highest cost. Batteries usually contain lithium, cobalt, manganese and graphite. Although these batteries contain high energy, they are also high in cost because they are made of rare metals. The prices of rare metals used in the production of batteries are increasing, especially as the demand for these metals increases worldwide. Mining and processing of materials such as lithium, cobalt and nickel are costly. In addition, the majority of these metals are concentrated in certain countries, which leads to price fluctuations due to supply-demand imbalances. The battery capacity of electric vehicles directly affects the battery cost. While the battery cost of short-range electric vehicles is lower, the battery cost increases with the battery growing as the range distance increases. The cost of batteries used in electric vehicles is high due to reasons such as the use of rare metals in the production of batteries and the complexity of the production processes. The decrease in the cost of battery production with developing technology is seen as a long-term goal.

It seems to be a significant problem for electric vehicles today, as there are not enough charging stations. While the number of electric vehicles is rapidly increasing, the problem of insufficient infrastructure is a negative situation for users. Charging stations are usually on main roads and are a problem for users living in rural areas. In addition, the high cost of charging stations and the environmental reasons that prevent users living in metropolitan areas from installing charging stations cause difficulties for users. The increasing popularity of electric vehicles requires the charging infrastructure to grow in parallel. However, in many countries, sufficient investment is not made in this regard. Especially in developing countries, states and the private sector need to make more efforts to invest in infrastructure projects. The development of charging infrastructure, usually in areas with high population density, can create inequality for users living in rural areas. For electric vehicles to become more widespread in the future, the rapid development of charging infrastructure and increasing its accessibility are of critical importance. The charging time of electric vehicles is one of the critical issues. The charging times of electric vehicles vary according to several factors. Battery capacity, type of charger, environmental conditions, charge status and battery health are the factors that affect charging time. Home chargers (AC Charging) are the slowest type of charging. They are usually used in standard 220V sockets in homes. Charging with this type of socket takes between 8 and 20 hours. Fast charging (DC charging) is available in stations and commercial areas such as shopping malls. These types of charging stations can charge in 30-40 minutes. Charging time is directly proportional to the size of the battery. Manufacturers recommend that the battery life of the vehicles should not fall below 20% and not exceed 80%. The details of the performance indicators for the improvements of the electric vehicle charging stations are demonstrated in Table 1.

**Table 1**  
Performance Indicators

Criteria
Financial Performance
Technological Improvements
Customer Expectations
Legal Effectiveness

### 3.2 Finding the Weights of the Indicators

The steps of DEMATEL are implemented to these criteria. The weighting results of these items are defined in Table 2.

**Table 2**  
Weighting Results

Criteria	Weighting Results
Financial Performance	2
Technological Improvements	1
Customer Expectations	4
Legal Effectiveness	3

It is concluded that technological improvement is the most essential performance indicator for the improvements of the electric vehicle charging projects. Financial performance and legal effectiveness also play a crucial role in this framework. However, customer expectation has the lowest weight.

#### **4. Conclusions**

This study highlights the importance of strategically aligning investments for the efficient establishment of EV charging stations. The findings of the research, based on DEMATEL technique, underscore technological improvements as the most vital factor for ensuring the success and performance of EV charging infrastructure. Moreover, the study emphasizes the significance of financial performance and legal frameworks, which are indispensable for the feasibility and long-term sustainability of these projects. For the efficient installation of EV charging stations, the development of fast charging technologies, energy efficiency and user-friendly interfaces is of great importance. Governments can ensure the rapid development of these technologies by encouraging R&D investments. In addition, incentives can be provided for the testing and dissemination of new charging technologies in cooperation with the private sector. The installation of EV charging infrastructure requires significant costs. Therefore, governments should provide tax incentives to the private sector. Regulatory frameworks need to be determined for the efficient installation of electric vehicle charging stations. Although customer expectations are of little importance in the charging station installation process, measures should be taken to increase user satisfaction. Regulations can be made to ensure that charging stations are easily accessible, fast and safe.

Electric vehicles are the center of attention today, and in parallel with this, they increase their sales share every year, and therefore bring new trends with different expectations. Today, it is seen that car users in the world are shifting from sedan models to SUV models, and in this period when many major car manufacturers have stopped producing sedan models that they have been producing for years and started producing SUVs with new names, electric car manufacturers have also started producing SUVs. It is expected that the battery capacities of electric vehicles will increase, their range will also increase with the increasing capacity, and new technological charging stations that can charge faster will be developed. It is expected that electric vehicles will become widespread by combining with autonomous driving technology. It is estimated that countries that start using electric buses for urban passenger transportation in the commercial vehicle sector will increase, and they will also start to be used in intercity buses and freight transportation. For all of these to happen, battery and charging technology must develop.

#### **Author Contributions**

Conceptualization, methodology, software, validation, formal analysis, investigation, M.F.Y., S.Y., and H.D.; resources, M.F.Y.; data curation, H.D.; writing—original draft preparation, writing—review and editing, M.F.Y., S.Y., and H.D.; supervision, H.D. All authors have read and agreed to the published version of the manuscript.

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#### **Data Availability Statement**

Data will be made available on request.

#### **Conflicts of Interest**

The authors declare no conflicts of interest.

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