Electric Vehicle Selection with Multi-Criteria Decision-Making Approach in European Market

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Abstract

Recently, the European Union has focused on reducing greenhouse gas emissions, which are mostly caused by the transportation sector. Thus, the adoption of electric vehicles as a green alternative is growing in popularity in European nations. With the increasing variety of models, there have been different electric vehicle alternatives for customers, which face different criteria when selecting it. The choice of an electric vehicle is based on a variety of technical factors, including cost, range, and battery capacity. Multi-Criteria Decision-Making techniques can resolve numerous competing criteria. To this end, we employ the entropy-integrated TODIM method to evaluate the performance of the top 10 electric vehicles. As per the empirical performance results of the TODIM method, Tesla Model 3 is found to be the best-performing EV whereas small-sized hatchbacks perform relatively worse in comparison to other electric vehicles. Besides, electric range is found to be the most influential criterion for electric vehicle selection. Increasing the electric range may also result in a large rise in sales. Thereby, this study aims to clarify the performance of electric cars sold to European customers.

Nomenclature

Data Envelopment Analysis	DEA
European Union	EU
Electric Vehicle	EV
Multi-Criteria Decision-Making	MCDM
TOmada de Decisao Interativa Multicriterio An acronym in Portuguese for Interactive Multi-Criteria Decision Making	TODIM

Keywords: Multi-Criteria Decision-Making, TODIM, Electric Vehicle Performance, Europe.

1. Introduction

High levels of pollution, rapid urbanization, and long-term reliance on fossil fuels for transportation damage the environment and people's health. The transportation sector is one of the leading areas in carbon dioxide emissions (Khan et al. 2020). Hence, Electric Vehicles (EVs) are regarded as eco-friendly tools for combating adverse effects on the environment (Ecer, 2021). The European Union (EU) has set strict targets to adopt EVs in member countries. By 2030, CO_2 emissions from vehicles are to be reduced by 55%, and those from vans by 50%, according to a recently proposed law. By 2035, it also suggests eliminating emissions from vans and cars (European Environment Agency, 2022). To accomplish these goals, there must be a major rise in the use of electric vehicles. EVs are gradually gaining market share in the EU. With the help of incentives put in place by the EU countries. Each year, the number of new electric car registrations has increased steadily (Koengkan et al. 2022). In this paper, we seek to provide a thorough framework for the analysis of EVs sold in Europe using Multi-Criteria Decision-Making (MCDM) techniques. Customers' preferences for EVs are waning because each model differs in terms of factors like driving range, battery capacity, and charging time (Ecer, 2021). MCDM methods can present a plausible solution in shedding light on the performance of conflicting criteria. We use the MCDM methodology to evaluate the performance of EVs sold in the EU as it can deal with conflicting criteria. The remainder of this study proceeds in that way. We briefly discuss the literature on EV performance studies in the following section. Next, we introduce the TODIM method (an acronym in Portuguese for Interactive Multi-Criteria Decision Making), which is one of the MCDM techniques that have lately been used by numerous researchers. We conduct the empirical analysis to demonstrate the suggested approach in the final section.

2. Literature Review

Performance evaluation of EVs has become popular within the last decade with the evolving EV market. A limited number of studies exist in the transportation literature about the performance evaluation of EV models. These studies are summarized as follows.

Ecer (2021) assessed the performance of EVs by using different MCDM techniques. Ecer (2021) employs acceleration, price, battery, and range as technical criteria to evaluate EVs. Price, permitted load, and energy consumption are found to be the three most important criteria for choosing an EV. Tesla Model S is determined to be the finest alternative among the evaluated EVs, according to Ecer (2021).

Sonar and Kulkarni (2021) evaluated the EVs sold in India via an integrated technique. They select driving range, battery capacity, driving range, price, torque, seating capacity, and charging time for performance evaluation. They use the AHP-integrated MABAC method to evaluate EV models. They first obtain criteria weights by the AHP technique. They carry out the EV performance evaluation by the MABAC technique, which is one of the novel MCDM approaches. They conclude that Hyundai Kona is found to be the best EV in India.

Ziemba (2021) assessed the EV market in Poland by various MCDM techniques. They determine acceleration, battery capacity, charging time, energy consumption, price, torque, top speed, and cargo volume as technical criteria. Ziemba (2021) concluded that all investigated MCDM methods indicate

Volkswagen Id 3 and Nissan Leaf are found to be the best-performing EVs in Poland. Ziemba (2021) also concludes that the results of implemented MCDM methods show great harmony.

Biswas and Das (2019) evaluated the performance of some EVs by the MABAC method, which is one of the novel MCDM approaches. They use energy consumption, price, top speed, acceleration, and range as technical criteria. They employ an integrated MCDM methodology to evaluate EVs. Initially, they determine criteria weights by the fuzzy AHP method. They use the MABAC technique to evaluate selected EVs. It has been discovered that the Hyundai Ioniq performs better than other EVs investigated.

Prakash and Mohanty (2017) evaluate the performance of 50 green cars by the Data Envelopment Analysis (DEA). Emission, braking, ride quality, acceleration, turning circle, and luggage capacity are selected as inputs, while torque and miles per gallon are determined as outputs. They select the output-oriented BCC model to determine the efficiency level of green cars. They conclude that 27 of the investigated models are found to be efficient.

3. Research Methods

3.1 The Entropy Method

Numerous methods exist for calculating weights for MCDM problems and the entropy method is an objective MCDM weighting technique, which can deal with human judgment (Wang et al. 2017). Presume that there are m options to assess n criteria $(x_{ij})_{m*n}$ is the decision matrix. The decision matrix is normalized below (Mavi et al. 2016).

$$p_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \quad (1)$$

The information entropy for every indicator is shown as follows:

$$E_j = - (\ln m)^{-1} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (2)$$

The weight obtained by the entropy method is revealed below:

$$w_j = (1 - E_j)/(n - \sum_{j=1}^{n} E_j) \quad (3)$$

$$0 \leq w_j \leq 1 \text{ and } \sum_{j=1}^{n} w_j = 1 \quad (4)$$

3.2 The TODIM Method

This MCDM technique is based on prospect theory's assessment of each alternative's dominance relative to other possibilities. After then, choices are sorted according to their dominance level (Lourenzutti, and Krohling, 2014; Yuan et al. 2019). The steps of the TODIM are given below (Wu et al. 2022; Alinezhad, and Khalili, 2019).

Step 1. Decision-Making Matrix

$$X=\begin{bmatrix} r_{11} & \cdots & r_{12} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{21} & \cdots & r_{22} & \cdots & r_{2n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (5)$$

$i = 1,2,\ldots.m \;\; j = 1,2,\ldots.m$

Step 2. Normalization of Decision-Making Matrix

The values are normalized based on Equations (6) and (7) for benefit and cost attributes, respectively.

$$r_{ij}^{*} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (6)$$

$$r_{ij}^{*} = \frac{\frac{1}{r_{ij}}}{\sum_{i=1}^{m} \frac{1}{r_{ij}}} \quad (7)$$

Step 3. Calculation of Relative Weights

The relative weight is calculated by Equation (8).

$$w_{jr} = \frac{w_j}{w_r} \quad (8)$$

Step 4. Calculation of the Dominance Degree

The difference value findings between indicators are used by the TODIM approach to reflect the deviation between indicators when determining relative dominance. The dominance function is computed by using Equation (9).

$$\emptyset_j(A_i, A_k) = \begin{cases} \sqrt{\frac{w_{jr}(x_{ij}-x_{kj})}{\sum_{j=1}^{n} w_{jr}}} & if\ x_{ij} > x_{kj} \\ 0 & if\ x_{ij=}x_{kj} \\ -\frac{1}{\theta}\sqrt{\sum_{j=1}^{n} w_{jr}(x_{ij}-x_{kj})/w_{jr}} & if\ x_{ij<}x_{kj} \end{cases} \quad (9)$$

where θ denotes the loss attenuation factor.

Step 5. Calculation of Overall Dominance Degree

The overall dominance degree of each alternative is calculated by employing Equation (6).

$$p\,(A_i, A_k) = \sum_{j=1}^{n} \emptyset_j(A_i, A_k) \quad (10)$$

$$\zeta_i = \frac{\delta_i - min\delta_i}{max\delta_i - min\delta_i} \quad (11)$$

Step 6. Ultimate Ranking of Alternatives

For the ultimate ranking of alternatives, they are ranked according to their overall dominance level.

4. Empirical Analysis

EVs have become increasingly popular due to increasing concerns about climate change. The EU is strict on decreasing CO_2 emissions by expanding the consumption of EVs. Therefore, consumers in Europe face many EV models with increasing alternatives in EVs. In our study, we aim to evaluate the top 10 selling EVs by the TODIM method. In this regard, we select the most important criteria for EV customers based on current studies (Ecer, 2021; Biswas and Das, 2019; Ziemba 2021). Top speed, electric range, torque, energy consumption, and price are determined as technical criteria. Of these technical criteria, top speed, electric range, and torque are benefit criteria, which are aimed at maximizing their values while energy consumption and price are criteria whose lower values are preferred. Table 1 list the technical criteria employed in our empirical analysis.

Table 1. Technical Criteria of Our Empirical Analysis

Technical Indicators	Definitions of Technical Indicators
Top Speed	The total amount of time needed to accelerate from 0 to 100 kph.
Electric Range	The furthest a fully charged battery can be driven before needing to recharge.
Torque	An engine's rotational force is expressed as a twisting force, and the amount of that twisting force that is available when the engine works is measured.
Energy Consumption	Consumption is measured in kilowatt-hours per 100 kilometers.
Price	The total amount of fee paid by customers to possess EVs.

In the first section of our investigation, we use the entropy approach to compute criteria weights. The weights computed using the entropy approach are shown in Table 2 as follows:

Table 2. Technical Criteria Weights Calculated via the Entropy Method.

Technical Indicators	Weights
Top Speed	0,104
Electric Range	0,277
Torque	0,253
Energy Consumption	0,193
Price	0,162

Source: Authors' Calculations.

We use the TODIM approach to establish the ranking of EVs after determining the weights of the criterion. In Table 3, we display the performance ranking outcomes of the EVs implemented using the TODIM approach.

Table 3. The TODIM method Performance Results of the Top Ten EVs in Europe.

Ranking	Top 10 EVs	Performance Ratings
1	Tesla Model 3	1
2	Hyundai Kona	0,8523
3	Peugeot 208	0,6875
4	Skoda Enyaq	0,4844
5	Vw id 4	0,4557
6	Vw id3	0,4307
7	Kia Niro	0,338
8	Fiat 500	0,2036
9	Renault Zoe	0,1901
10	Vw Up	0

Source: Authors' Calculations.

As TODIM method results indicate, Tesla Model 3 is found to be the best-performing EV among the most sold alternatives. On the other hand, VW Up, which takes place among the A segment, is found to be performing worse in comparison to other most-sold EVs. The TODIM method normalizes the dominance to a range of 0-1 to make the performance ranking more understandable. Hence, the value of 0 does not mean that the relevant alternative has not performed at all. This value indicates the relatively weakest performance. Our analysis results indicate that A and B segments representatives of the hatchbacks namely Fiat 500, Renault Zoe, and VW Up demonstrate insufficient performance ratings. Besides, it should be emphasized that these performance ratings may differ based on the selected criteria and investigated MCDM methods.

5. Conclusion

In our analysis, we use the TODIM technique, an MCDM approach, to evaluate the performance of EVs. To date, MCDM approaches have been implemented in various research fields. The performance evaluation of EVs is one of those fields, in which researchers employ MCDM methods. When there are conflicting criteria, MCDM techniques are particularly suitable to evaluate the performance of alternatives. Selecting the most suitable alternative for consumers may be very challenging. To this end, an effective approach is the assessment of EVs using a hybrid MCDM approach from the perspective of consumers. We first calculate the criteria weights using the entropy approach. Second, we use the entropy-integrated TODIM approach to assess the EVs offered for sale in Europe. The electric range is identified as the most influential technical factor among those under investigation, according to empirical results obtained using the entropy approach. The electric range is regarded as one of the main handicaps of electric vehicles for consumers. Rising electric range may provide an increase in sales. TODIM method results indicate that is Tesla Model 3 is found to be the best-performing EV among the top ten sold in Europe. This EV outperforms other alternatives in terms of all criteria investigated. The analysis results indicate that the electric range is found to be the most influential criterion. Tesla Model 3 and Hyundai Kona possess significant electric range values. On the other hand, small hatchbacks namely Vw Up, Renault Zoe, and Fiat 500 have a relatively lower electric range, top speed, and torque values. These low values of small EVs affect their performance negatively. These results indicate that if consumers wish for performance-oriented vehicles, they should abstain from buying these small-scaled EVs. In this regard, consumers should determine their priorities while buying an EV as the superior features of the models may differ significantly. Our analysis results are based on the selected criteria and may differ if other technical criteria are selected for performance evaluation.

We can conclude that MCDM techniques are very useful methods for handling performance evaluation with several competing criteria. EV selection involves a variety of performance factors. As a result, the TODIM method can be viewed as a good strategy since it takes into account how dominant each alternative is compared to other alternatives. The findings of our investigation reveal an overall evaluation of EVs for consumers.

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