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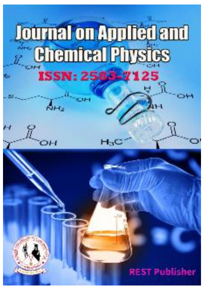


# Performance Assessment of Battery Electric Vehicles Using the TOPSIS Method

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***Abstract:*** *Worldwide interest in "hybrid and battery electric vehicles" has increased recently as a result of their ability to save on fuel, lessen reliance on foreign oil, and reduce greenhouse gas emissions. The effectiveness of the sub-systems that these vehicles are built with determines their overall success in large part. It is necessary to estimate these subsystems' parameters with great accuracy to improve their performances. "Battery electric vehicles (BEVs)", an eco-friendly type of vehicle, are crucial given that the automotive industry contributes significantly to carbon emissions. Due to the recent quick growth of the BEV market, it has grown to be a substantial challenge to evaluate BEV alternatives fully from the perspective of the consumer. By examining the fundamental characteristics of each BEV, this evaluation can be made. The use of "multiple criteria decision making (MCDM)" techniques is a useful tool for making the best BEV buying choice. Therefore, six BEVs are selected as options in this work. These vehicles are then ranked using TOPSIS based on technical specifications, such as Battery capacity, Range, Top speed, Quick charge time, Acceleration and Purchasing price. In this study TOPSIS method analyses the rank of Mercedes-Benz EQS as first, Audi e-tron GT as fourth, Porsche Taycan as fifth, Audi e-tron as third, Audi RS e-tron GT as second and Mercedes-Benz EQC as sixth. So, the result from the TOPSIS method shows that Mercedes-Benz EQS is highlighted as the best choice of the selected battery electric vehicles followed by the Audi RS e-tron GT.*

***Keywords:*** *BEVs, internal combustion engine vehicles, top speed, quick charge time, acceleration and purchasing price and MCDM.*

## 1. INTRODUCTION

Alternative automobiles like hybrid and battery electric vehicles are getting more attention from the automobiles industry and scientific community due to increasing concern about the depletion of the planet's petroleum resources, increased CO2 emissions, and global warming issues brought on by the widespread use of conventional "internal combustion engine vehicles (ICEVs)"[1]. According to recent studies, the study of estimating methodologies, along with battery technologies, vehicle control, charging, and grid engagement difficulties, is one of the primary areas of interest in the field of electric vehicles. Assessment of any defect, condition, or information is crucial for assuring the stability and dependability of a vehicle. [2]. The best estimate of any element makes it easier to sense, monitor, and manage it than correct measurement, which is frequently challenging in practice and requires expensive equipment. Therefore, "estimation" has developed into a growing research field that aids in the technological growth of the market for hybrid and electric vehicles. Consequently, over the past few years, there has been a sharp increase in the number of studies published in journals and conference proceedings. [3]. Electric vehicles (EVs) that run on batteries are thought to be a possible answer to energy and environmental problems. The development of an effective, dependable, and affordable electrical propulsion system (EPS) for battery-powered EVs is made possible by advancements in traction motors and battery technologies. The permanent magnet synchronous motor (PMSM), which performs well when compared to other utilised motors, is typically used in electric vehicles. Moreover, due to their high energy densities and prolonged lifetimes, lithium-ion batteries are mostly employed to supply motoring power. [4]. Both "battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)" are currently regarded as crucial routes to achieving future impact on the environment standards. The EV drive capability needs to grow for these innovations to be effective alternatives to traditional cars ("powered by combustion engines") for transportation over long distances. Lower vehicle mass or an increase in overall power storage ("size of the battery pack") can accomplish this. Utilizing multipurpose materials or constructions that can integrate two or more roles is an alternative design strategy. [5,6]. "Integrated structural energy storage" is one such remedy. In the frame members of a structural element, this kind of substance or structure can store electrical energy. With this material/structure, it is possible to increase overall energy storage while maintaining or even reducing vehicle weight. Additionally, this material/structure allows for the distribution of energy storage, which eliminates the requirement for cables, and gives significant volume savings on a system level. Integrated structural energy storage, sometimes known as "massless" energy storage thanks to its versatility, can transform the design of electric cars in the future. [7,8]. Because it makes economic and environmental sense, the use of renewable clean energy for transportation and other purposes is already increasing more quickly in many developing countries than in wealthier ones. Globally, the use of electricity is becoming more electrified, giving countries a chance to reduce their transportation-related GHG emissions. Environmental and financial advantages of adopting electric vehicles [9]. The technological, infrastructural, economic, and key issues are preventing EVs from becoming more widely used. By properly utilising technology in the areas of "material science, electrical energy conversion, battery management, and electricity generation", among other things, these difficulties might be lessened. To offer infrastructure support and create regulations that will draw more manufacturers and consumers into the field of EVs, various government entities and significant stakeholder support are necessary. [10]. The use of "multiple criteria decision making (MCDM)" techniques is a useful tool for making the best BEV buying choice. Therefore, six BEVs are selected as options in this work. Six BEVs selected as alternatives are “Mercedes-Benz EQS, Audi e-tron GT, Porsche Taycan, Audi e-tron, Audi RS e-tron GT and Mercedes-Benz EQC”. Technical specifications, such as “battery capacity, range, top speed, quick charge time, acceleration and purchasing price” are taken as evaluation parameters.

## 2. MATERIALS AND METHODS

"Life cycle analysis, statistical techniques, MCDM methods, and other methodology" have all been used to evaluate new generation vehicles to date. Among them, the MCDM nomenclature has come to be seen as a promising set of techniques. Consequently, MCDM techniques were also used in this work. Making the optimum BEV purchase decision requires the use of "multiple criteria decision-making (MCDM)" methodologies. "Hwang & Yoon" introduced the "Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)". This strategy is based on employing the perfect solution; if an alternative is more favourable than the ideal solution, it will be regarded as the best option. [11,12]. The straightforward computing process is used by the well-known and dependable TOPSIS approach. The chosen option in the TOPSIS approach should be the one that is the closest to the positive ideal solution and the furthest from the negative ideal solution [13]. Total rank reversal, where the order of preferences is fully inverted and the alternative that was previously judged to be the best now becomes the worst, can occasionally occur when an alternative is added to or removed from the process. Such a phenomenon might not be acceptable in many situations [14,15]. In MCDM, a variety of options must be looked at and assessed depending on some factors. The goal of MCDM is to help the decision-maker choose from a variety of options. As a result, practical problems are typically described by a variety of conflicting criteria, and no solution may be able to fulfil all of the criteria at once. The solution is thus a compromise choice depending on the decision preferences. maker's Thus, TOPSIS is based on the principle that the best outcome should be the one that is most dissimilar from the Negative Ideal Solution (NIS) and most similar to the Positive Ideal Solution (PIS) (NIS). The final ranking is calculated using the closeness measure [16,17]. The TOPSIS approach is used in this research project to evaluate and rank battery electric vehicles. The TOPSIS approach uses the following processes to rank alternatives.

**Step 1:** The decision matrix X, which displays how various options perform concerning certain criteria, is created.

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

**Step 2:** Weights for the criteria are expressed as

$$w_j = [w_1 \cdots w_n], \quad where , \sum_{j=1}^{n}(w_1 \cdots w_n) = 1 \quad (2)$$

**Step 3:** The matrix $x_{ij}$'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sqrt[2]{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

Weighted normalized matrix $N_{ij}$ is calculated by the following formula

$$N_{ij} = w_j \times n_{ij} \quad (4)$$

**Step 4:** We'll start by determining the ideal best and ideal worst values: Here, we must determine whether the influence is "+" or "-." If a column has a "+" impact, the ideal best value for that column is its highest value; if it has a "-" impact, the ideal worst value is its lowest value.

**Step 5**: Now we need to calculate the difference between each response from the ideal best,

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^+)^2} \quad for\ i \in [1, m]\ and\ \ j \in [1, n] \quad (5)$$

**Step 6:** Now we need to calculate the difference between each response from the ideal worst,

$$S_i^- = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^-)^2} \quad for\ i \in [1, m]\ and\ \ j \in [1, n] \quad (6)$$

**Step 7:** Now we need to calculate the Closeness coefficient of $i_{th}$ alternative

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad where, 0 \leq CC_i \leq 1, i \in [1, m] \quad (7)$$

The Closeness Coefficient's value illustrates how superior the alternatives are in comparison. A larger $CC_i$ denotes a substantially better alternative, whereas a smaller $CC_i$ denotes a significantly worse alternative.

Six BEVs selected as alternatives are "Mercedes-Benz EQS, Audi e-tron GT, Porsche Taycan, Audi e-tron, Audi RS e-tron GT and Mercedes-Benz EQC". Technical specifications, such as "battery capacity, range, top speed, quick charge time, acceleration and purchasing price" are taken as evaluation parameters.

**Battery Capacity:** As measured in ampere-hours, battery capacity is the entire quantity of electricity produced by the battery's internal electrochemical processes. For instance, a 5 Ah battery can be discharged at a steady rate of 1 C (5 A) for one hour. The typical capacity is about 40 kWh; however, some newer automobiles can hold up to 100 kWh. The vehicle's range will directly depend on the size of its batteries. The greater the kWh value, the more miles you can go on a single charge [18].

**Range:** The term "range" describes how far an electric or hybrid car can go before its battery needs to be recharged. The lithium-ion battery's capacity, or the quantity of electricity it can store, determines an electric vehicle's range in the first place. It is equivalent to the size of the fuel tank in combustion-powered vehicles when expressed in kWh (kilowatt hours), and it establishes the gas reserves accessible to the motor and other components of the vehicle. The residual range of the electric car is consequently determined by the amount of energy in the battery at any particular time [19].

**Top Speed:** The electric vehicle's highest speed is the fastest it can go. Performance is vital to you if you're seeking the fastest electric automobile. Some of the quickest electric vehicles may reach top speeds of over 250 mph, however, some of these come at a higher price. Nevertheless, a lot of electric vehicles have little trouble exceeding 100 mph. As of right now, electric vehicles may have a somewhat slower top speed than gas-powered ones (depending on the manufacturer) [20].

**Quick Charge Time:** Unsurprisingly, buyers evaluate technological aspects while considering whether to buy an electric vehicle. Some researchers have examined the function of rapid charging time. Rapid charging in unfavourable weather conditions is a crucial car feature that supports the adoption of BEVs. Consumers are more likely to accept BEVs with quick charging times [21].

**Acceleration:** Measures how rapidly an electric vehicle can accelerate from a standstill to 60 mph in a given amount of time. Acceleration speeds are shorter in electric automobiles than in gas-powered ones because of the instant torque they have because the engine powers the wheels directly. To decide which electric car has the greatest result to meet your requirements, we utilise acceleration to gauge rapidity. Performance scores will be aided by the electric vehicles with the quickest acceleration [22].

**Purchasing Price:** The cost of buying a BEV is often discussed in the literature as a major deterrent to doing so. Given their advanced technologies, it is not unexpected that electric vehicles have high buying costs. In other words, it has been established that high purchasing costs are a barrier to BEV sales and adoption. According to the attitude of consumers in India toward BEVs, as in other countries, the acquisition cost of electric vehicles represents one of the most important factors [23].

## 3. ANALYSIS AND DISCUSSION

**TABLE 1.** performance data of battery electric vehicles

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| BEV1 | 107.8 | 857 | 210 | 30 | 4.3 | 15500000 |
| BEV2 | 93.4 | 500 | 245 | 33 | 4.1 | 17000000 |
| BEV3 | 79.2 | 395 | 240 | 22 | 5.4 | 15300000 |
| BEV4 | 95 | 484 | 200 | 22 | 5.7 | 10200000 |
| BEV5 | 93.4 | 481 | 250 | 19 | 3.3 | 19300000 |
| BEV6 | 80 | 471 | 180 | 40 | 5.1 | 9950000 |

Table 1 shows the performance data of selected battery-electric vehicles. In this paper Battery capacity (min)(C1), Range (km) (C2), Top speed (km/hr) (C3), Quick charge time (min) (C4), Acceleration (sec) (C5), Purchasing price (₹) (C6) and alternatives as Mercedes-Benz EQS (BEV1), Audi e-tron GT(BEV2), Porsche Taycan (BEV3), Audi e-tron (BEV4), Audi RS e-tron GT(BEV5) and Mercedes-Benz EQC(BEV6).

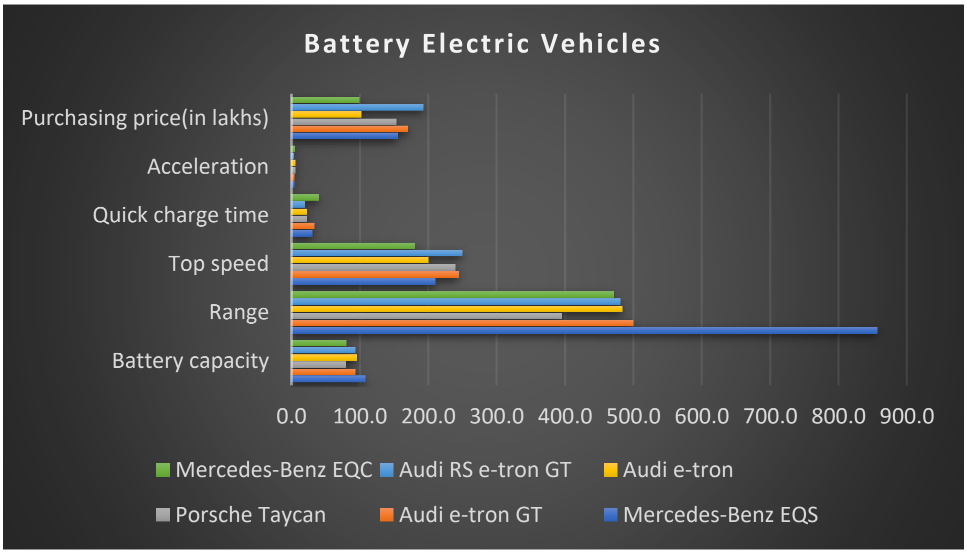


**FIGURE 1.** performance data of battery electric vehicles

Figure 1 shows a graphical view of the performance of battery-electric vehicles. In this paper Battery capacity (min)(C1), Range (km) (C2), Top speed (km/hr) (C3), Quick charge time (min) (C4), Acceleration (sec) (C5), Purchasing price (₹) (C6) and alternatives as Mercedes-Benz EQS (BEV1), Audi e-tron GT(BEV2), Porsche Taycan (BEV3), Audi e-tron (BEV4), Audi RS e-tron GT(BEV5) and Mercedes-Benz EQC(BEV6).

**TABLE 2.** Normalized Data

| | | | | | |
|---|---|---|---|---|---|
| 0.4784 | 0.6339 | 0.3856 | 0.4278 | 0.3717 | 0.4236 |
| 0.4145 | 0.3698 | 0.4498 | 0.4706 | 0.3544 | 0.4646 |
| 0.3515 | 0.2922 | 0.4407 | 0.3137 | 0.4668 | 0.4181 |
| 0.4216 | 0.3580 | 0.3672 | 0.3137 | 0.4927 | 0.2788 |
| 0.4145 | 0.3558 | 0.4590 | 0.2709 | 0.2852 | 0.5275 |
| 0.3551 | 0.3484 | 0.3305 | 0.5704 | 0.4408 | 0.2719 |

The normalized matrix of the Ratings of the Manufacturing Processes is displayed in Table 2 above. This matrix was produced using equation three.

**TABLE 3.** Weight

| | | | | | |
|---|---|---|---|---|---|
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |

The preferred weight for the evaluation parameters is shown in Table 3. In this case, weights are equally distributed among “productivity, accuracy, quality, and operation cost”. The sum of weights distributed equals one.

**TABLE 4.** Weighted normalized decision matrix

| | | | | | |
|---|---|---|---|---|---|
| 0.0797 | 0.1056 | 0.0643 | 0.0713 | 0.0619 | 0.0706 |
| 0.0691 | 0.0616 | 0.0750 | 0.0784 | 0.0591 | 0.0774 |
| 0.0586 | 0.0487 | 0.0734 | 0.0523 | 0.0778 | 0.0697 |
| 0.0703 | 0.0597 | 0.0612 | 0.0523 | 0.0821 | 0.0465 |
| 0.0691 | 0.0593 | 0.0765 | 0.0452 | 0.0475 | 0.0879 |
| 0.0592 | 0.0581 | 0.0551 | 0.0951 | 0.0735 | 0.0453 |

Table 4 shows the weighted normalized matrix of the decision matrix and it is calculated by table 2 and table 3 using equation 4.

**TABLE 5.** Positive Matrix

| | | | | | |
|---|---|---|---|---|---|
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |
| 0.0797 | 0.1056 | 0.0765 | 0.0951 | 0.0821 | 0.0879 |

Table 5 shows the positive matrix calculated by using table 4. The ideal best for a column is the maximum value of that column in table 4.

**TABLE 6.** Negative matrix

| | | | | | |
|---|---|---|---|---|---|
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |
| 0.0586 | 0.0487 | 0.0551 | 0.0951 | 0.0821 | 0.0879 |

Table 6 shows the negative matrix calculated by using table 4. The Ideal best for a column is the minimum value in that column in table 4.

**TABLE 7**. SI Plus and Si negative

| | SI Plus | Si Negative |
|---|---|---|
| **Mercedes-Benz EQS** | 0.037696 | 0.071039 |
| **Audi e-tron GT** | 0.054501 | 0.039891 |
| **Porsche Taycan** | 0.076689 | 0.050177 |
| **Audi e-tron** | 0.07737 | 0.061988 |
| **Audi RS e-tron GT** | 0.077124 | 0.066089 |
| **Mercedes-Benz EQC** | 0.070954 | 0.044459 |

Table 7 shows the Si plus and Si negative values. The difference between each response from the "ideal best ($S_i^+$)" is found utilizing equation 5 and the difference between each response from the "ideal worst ($S_i^-$)" is found utilizing equation 6.

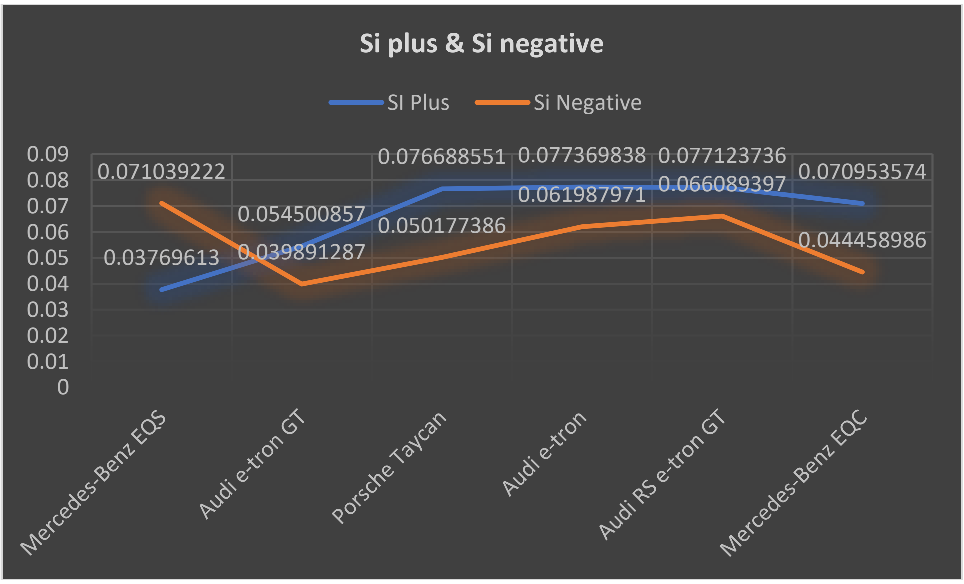


**FIGURE** 2. SI Plus and Si negative

Figure 2 illustrates the graphical representation of the Si plus and Si negative values. The difference between each response from the “ideal best ($S_i^+$)” is found utilizing equation 5 and the difference between each response from the “ideal worst ($S_i^-$)” is found utilizing equation 6.

**TABLE 8**. Closeness coefficient

| BEV | Ci |
|---|---|
| **Mercedes-Benz EQS** | 0.653322 |
| **Audi e-tron GT** | 0.422612 |
| **Porsche Taycan** | 0.395515 |
| **Audi e-tron** | 0.444812 |
| **Audi RS e-tron GT** | 0.461476 |
| **Mercedes-Benz EQC** | 0.385218 |

The proximity coefficient values of the alternatives are displayed in Table 8. Equation 7 is employed in the calculation. Here Closeness coefficient value for Mercedes-Benz EQS is 0.653322, Audi e-tron GT is 0.422612, Porsche Taycan is 0.395515, Audi e-tron is 0.444812, Audi RS e-tron GT is 0.461476 and Mercedes-Benz EQC is 0.385218.

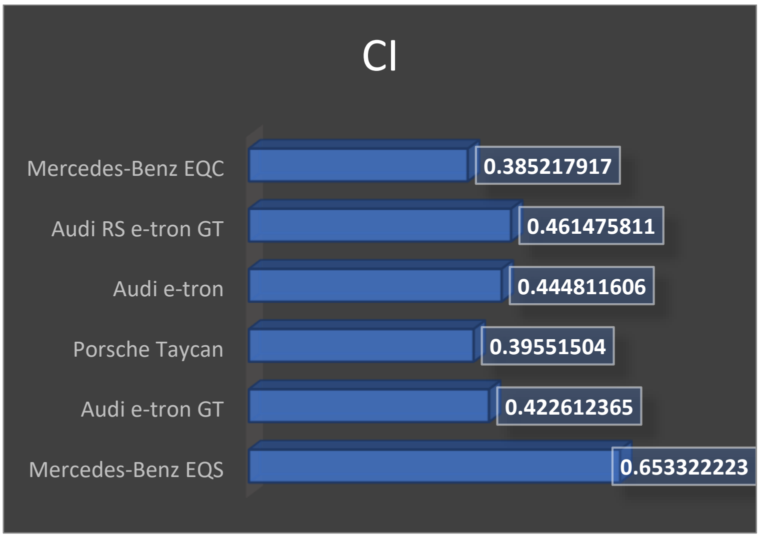


**FIGURE 3.** Closeness Coefficient (CCi)

Figure 3 illustrates the graphical representation of CCi. It is calculated by using equation 7. Here Closeness coefficient value for Mercedes-Benz EQS is 0.653322, Audi e-tron GT is 0.422612, Porsche Taycan is 0.395515, Audi e-tron is 0.444812, Audi RS e-tron GT is 0.461476 and Mercedes-Benz EQC is 0.385218.

**TABLE 9.** Rank

| BEV | Rank |
|---|---|
| **Mercedes-Benz EQS** | 1 |
| **Audi e-tron GT** | 4 |
| **Porsche Taycan** | 5 |
| **Audi e-tron** | 3 |
| **Audi RS e-tron GT** | 2 |
| **Mercedes-Benz EQC** | 6 |

Table 9 shows the rank of the performance of battery electric vehicles. Here rank of Mercedes-Benz EQS is first, Audi e-tron GT is fourth, Porsche Taycan is fifth, the Audi e-tron is third, Audi RS e-tron GT is second and Mercedes-Benz EQC is sixth.

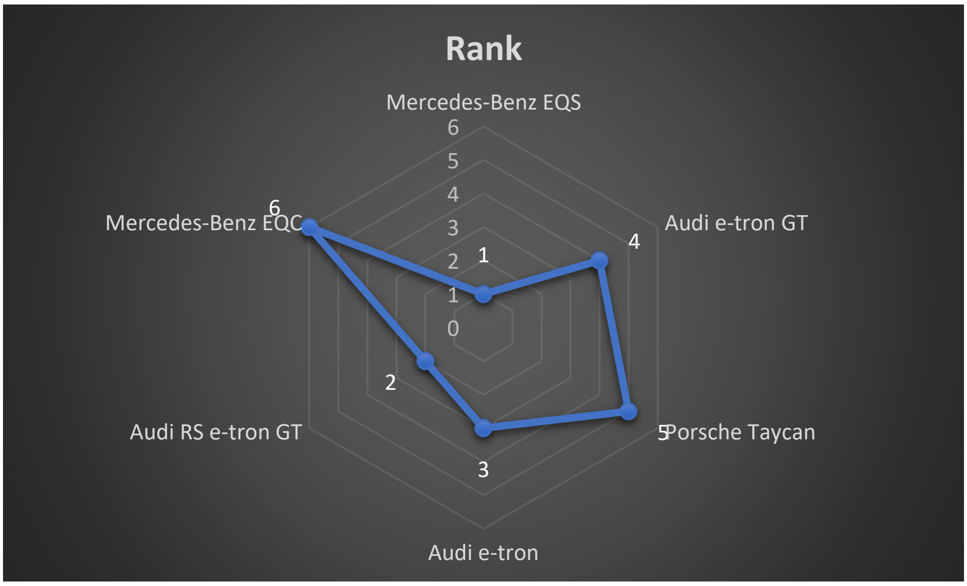


**FIGURE 4.** Rank

Figure 4 illustrates the ranking of Ui from Table 9. Here rank of alternatives using the TOPSIS method for Mercedes-Benz EQS is first, Audi e-tron GT is fourth, Porsche Taycan is fifth, Audi e-tron is third, Audi RS e-tron GT is second and Mercedes-Benz EQC is sixth. In this paper from the TOPSIS method Mercedes-Benz EQS is highlighted as the best choice of the selected battery electric vehicles followed by the Audi RS e-tron GT.

## 4. CONCLUSION

The amount of pollution on the earth is increasing, and every attempt is being made to cut CO2 emissions and rescue the environment. The development of electric automobiles is one such initiative (EV). Being one of the largest producers of CO2 emissions, the transportation industry must be transformed into a green one. To stay up with the worldwide development of EVs, the Indian government has developed ambitious plans to introduce EVs to the Indian market. The acceptance of cars operated by alternative fuels during the past ten years is a consequence of the worldwide desire to cease transportation dependence on the petroleum industry. Modern propulsion system electrification makes sustainable road networks possible. The scientific, organizational, commercial, and policy issues are preventing EVs from becoming more widely used. By properly utilising technology in the areas of materials engineering, electric power conversion, battery management, and power generation, among other things, these difficulties might be lessened. To create regulations that will encourage more manufacturers and consumers to invest in the field of EVs, infrastructure support from some government agencies and significant stakeholder groups is necessary. In this study TOPSIS method analyses the rank of Mercedes-Benz EQS as first, Audi e-tron GT as fourth, Porsche Taycan as fifth, Audi e-tron as third, Audi RS e-tron GT as second and Mercedes-Benz EQC as sixth. So, the result from the TOPSIS method shows that Mercedes-Benz EQS is highlighted as the best choice of the selected battery electric vehicles followed by the Audi RS e-tron GT.

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