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Utilizing an integrated AHP-COPRAS approach for battery selection in electric vehicles

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ABSTRACT

Internal combustion engine vehicles provide better performance and longer-range using fossil fuels such as gasoline and diesel. However, fossil fuels are non-renewable and cause environmental pollution, alternative fuels such as blends of ethanol and biodiesel, hydrogen etc have been sought for these vehicles. On the other hand, some researchers prefer to design alternative vehicles such as hybrid and electrical vehicles, instead of changing the fuel type. Among the studied topics for alternative vehicles, the battery is one of the most important components, especially in electrical vehicles. Batteries are diversified with different criteria such as battery life, nominal voltage, energy density, volumetric energy density, specific power, operating temperature, and production cost. In this study, the expert perspective was utilized when selecting the battery type to be employed for the energy source through utilizing the Integrated Analytical Hierarchy Process (AHP) - Complex Proportional Assessment (COPRAS), a multi-criteria decision-making approach. Various batteries such as Lead-acid (Pb-acid), Nickel-cadmium (Ni-Cd), Ni-MH, Sodium Nickel Chloride (Zero Emission Battery Research Activity-ZEBRA), Lithium –Ion (Li-Ion) Battery were evaluated in terms of different criterion. Among the alternatives the Li-ion battery type is chosen as the best option and the Ni-Cd battery is the least chosen alternative.

Keywords: Battery Selection, Electric Vehicle, AHP, COPRAS, Multi-Criteria Decision-Making

1. Introduction

Traditional automobiles, also known as internal combustion engine vehicles (ICEVs), are often used because of their efficiency and accessibility to fuel. However, they run on fossil fuels and emit dangerous pollutants including carbon monoxide, nitrogen oxides and unburn hydrocarbons. Particularly, the transportation industry is the source of these dangerous exhaust gases. It has been demonstrated that these gases substantially affect the health of living beings, particularly humans [1]. Concerns regarding climate change have driven the need for eco-conscious substitutes for regular internal combustion engine (ICE) cars, aiming to cut down on greenhouse gas and carbon discharges. Electric vehicles (EVs) are gaining traction as an environmentally mindful, reduced-carbon, and enduring substitute for internal combustion engines (ICEs) [2]. Since their historical growth began in the 19th century, electric vehicles (EVs) have gained popularity, especially in light of the rise in greenhouse gases and air pollution brought on by internal combustion engines. The quantity of EVs in operation has surged significantly over the past ten years, rising from 17,000 in 2010 to over 15 million by 2021 [3]. According to Turkish Standard Instute, there are 14,706,162 registered vehicles in Türkiye. Approximately 98.5% of the registered vehicles are fossil-fueled (27.8% gasoline, 36.4% diesel, 34.3% LPG), 1.2% hybrid, and 0.2% electrical vehicles [4].

Studies on various EV kinds are becoming more prevalent every day. Three categories best describe the types of EVs now in use. The first item that typically springs to mind is EVs, also known as All Electric Vehicles, which derive all of their energy from a battery pack. Recently, as battery technology has advanced, interest in all-electric vehicles has grown. However, hybrid electric vehicles—which combine an internal combustion engine with an electric motor for propulsion—are among the most popular types of EVs today. The literature refers to another form of EV as fuel cell electric vehicles that use hydrogen energy [5].

Compared to cars powered by internal combustion engines, electric vehicles use quite different technology. These automobiles utilize electric motors that utilise electric energy [6]. Parts used in energy storage and conversion include batteries, fuel cells, and supercapacitors, which are all members of the energy converter family. To meet the varied energy needs of different devices and systems, all three are necessary. However, they are unable to handle all applications on their own [7].

Batteries are the essential power source for electric vehicles, utilizing chemical reactions to supply energy for vehicle functioning. This approach obviates the necessity for fossil fuels, provided the electricity fueling EVs originates from sustainable sources. During discharge, batteries transform chemical energy into electrical energy, and during charging, they reverse this process, converting electrical energy back into chemical energy. Batteries serve as reliable storage units for energy, offering diverse power and capacity options. Achieved by connecting battery cells in series or parallel, this flexibility enables their application in various contexts.

The batteries in EVs are their most costly component. EV battery costs were on average \$750/kWh in 2010, \$500/kWh in 2012, and \$380/kWh in 2014. Since then, the cost has dropped significantly. It is predicted that the unit cost of EVs would reduce as a result of this anticipated decline, increasing consumer buying power [8]. Battery technology is the most important piece of technology for the creation of electric cars. The battery types that will be employed in this study will be briefly described before delving into the specifics of the battery chemistry of electric cars [9].

Lead-acid (Pb-Acid) Battery: Lead-acid batteries are the most traditional and well-known kind of rechargeable batteries. This battery technology is so popular across the world for several reasons. The technology that underpins lead-acid batteries is straightforward, affordable to produce, widely used, and simple to build. The comparatively compact batteries are strong and dependable, and they require almost little maintenance. They also fit easily inside the engine compartment. The relatively short cycle life and working life of the battery, however, are the limiting considerations for these batteries. Lead-acid batteries typically last 5 to 15 years [10] or 1200 to 1800 charge-discharge cycles.

Nickel-cadmium (Ni-Cd) Battery: Nickel-cadmium batteries have a long lifespan and may be completely depleted without suffering any harm. It discharges current at a rapid rate. Higher specificity and gravitational energy density than lead-acid batteries. Both its power and cycle life are longer. The expensive nature of this battery is one of the factors limiting its utilisation. The high expense of recycling the material is the major cause of this. Cadmium is a heavy metal that is exceedingly hazardous and may pollute the environment if improperly disposed of [11].

Ni-MH Battery: The most popular nickel-based battery is the Ni-MH, which entered the market in 1991. Compared to lead-acid and nickel-cadmium batteries, it has a higher weight energy density and specific power. But they are also more expensive than lead-acid batteries due to the greater price of nickel and hydride-storing metals. They are free of poisonous substances. Ni-MH batteries are not promising batteries because of the high nickel content and high nickel costs. Ni-MH batteries are not promising batteries because of the high nickel content and high nickel costs [12].

ZEBRA Battery: Zebra batteries are another name for Sodium Nickel Chloride (NaNiCl) batteries. The project "Zero Emission Battery Research Activity" gave rise to the moniker Zebra. Lead acid and nickel-based batteries have lower energy density and nominal voltage values. This battery's drawbacks are low specific power, self-discharge issue, and temperature control [8].

Li-Ion Battery: When compared to other battery types like Pb-acid and Ni-MH, Li-ion batteries stand out as one of the most innovative energy storage options due to their properties like high energy and power densities and extended shelf lives. There is a lot of energy that can be held per unit of weight and volume. However, the lifespan of a lithium-ion battery is temperature-dependent; at higher temperatures, ageing occurs considerably more quickly, and deep discharges significantly shorten the cycle life. Li-ion batteries are particularly vulnerable to overcharging and deep discharge, which can harm them, decrease their lifespans, and even put them in risky circumstances [13].

In multi-criteria decision-making, first, the problem is determined, then the problem is structured and the result is reached by using the model. The processes they follow are normalization of data, weighting of criteria and ranking of alternatives. There are many weighting methods in the literature such as AHP, SWARA, CRITIC, ENTROPY, and DEMATEL decision-making methods in the literature. Such as AHP, ANP, TOPSIS, ARAS, WASPAS, CODAS, COPRAS, MABAC, MAIRCA [14]. MCDM is used in almost every area where the decision is needed such as Chemistry [15], Earth and Planetary Sciences [16], Economics, Econometrics and Finance [17], Material Science [18], Energy [19, 20, 21, 22, 23, 24, 25], Agricultural and Biological Science [26] Environmental Science [27,28] , Decision Science [29,30], Business, Management and Accounting[31], Engineering[32,33], Computer Science [34,35].

Loganathan et al. developed a multi-criteria decision-making technique-based methodology, with categories depending on cathode/anode material for the selection of Li-ion batteries. The technique helps original equipment manufacturers of electric vehicles choose the optimum battery and optimize the price and efficiency of electric vehicles. The Lithium-Titanate ($Li_4Ti_5O_{12}$) battery was shown to be the best all-around battery appropriate for electric vehicle applications as a consequence of the presented technique [36].

Sonar and Kulkarni sought to present the best alternative in current electric vehicles by combining the analytical hierarchy process (AHP) and the multi-attribute boundary approach area comparison (MABAC) method as a multi-criteria decision-making tool (MCDM) for the selection and ranking of the best alternative. According to the AHP weighting, the driving range received more attention from the experts. The Hyundai Kona is picked as the top option based on the performance selection criteria used in the MABAC approach since it has the greatest performance score of all the alternatives considered. For clients looking for inexpensive cars where price is a major concern, Tata Tigor has done well [37].

Chakraborty and Saha used a multi-criteria group decision making (MCGDM) approach to determine the optimal recycling strategy for Lithium-Ion Batteries in a Fermatean fuzzy environment (FFE). Under FFE, a new entropy measure (EM) and numerous aggregation operators (AOs) have been added. According to the proposed method, the best alternative for lithium-ion battery (LIB) recycling is "a combination of mechanical shredding (MS), electrolyte extraction (EE), electrode dissolution (ED), and cobalt electrochemical reduction (CECR) [38].

Wu et al. present a decision assistance tool for assessing commercial (small-scale) energy storage devices. It then determines the best option(s) depending on the preferences of the users. The ranking findings clearly illustrate that user preferences have a significant influence on the recommended energy storage solutions [39]. For the thorough assessment of battery energy storage systems, Zhao et al suggested an integrated fuzzy-MCDM (multi-criteria decision making) model incorporating the Fuzzy-Delphi methodology, the Best-Worst method (BWM), and fuzzy-cumulative prospect theory (CPT). The empirical results reveal that Li-ion batteries are the preferred choice for micro-grid demonstration projects, followed by NaS batteries and NiMH batteries. Even if decision makers and investors have different risk preferences, the results show that when considering technological, environmental, economic, social, and performance factors, the Li-ion battery is still the best, followed by the NaS battery [40].

Yücenurşen and Sabancı investigated Different battery types for use in converting a small and light (600-1000 kg) ICE vehicle into an electric vehicle. The investigation was carried out to guarantee that this vehicle is acceptable for urban use and has a range of about 100 kilometers. Each battery technology's capacity is estimated to be around 15 kWh. When doing the techno-economic study of various battery types, it was taken into account that they delivered the required energy for about ten years. For comparison, seven different battery technologies (lead-acid, gel, Ni-Cd, Li-Ion, $LiFePo_4$, LiPo, and Ni-MH) were employed. Price assessment in US Dollars ($), 10-year investment cost, weight and volume values, as well as weight and volume values necessary to create 1 kWh of energy, were included in the analysis tables. The analysis found that the cheapest technology for a 10-year lifetime was lead-acid technology. Lead-acid technology is 30% less costly than the second-cheapest gel technology and 82% less expensive than the most expensive technology, LiPo technology. The investigation discovered that the lightest technology was LiPo. This technique has been proven to be 85% lighter than gel technology. Aside from this information, tabular statistics on cycle life, self-discharge, benefits and downsides are provided [41].

The goal of this article is to select the best battery type for electric cars that also fits the distinctive criteria specified by experts, from among the five various battery types analyzed. The AHP approach, a multi-criteria decision-making process, will be researched to assess the weight of each criterion and then choose the best alternative among the given batteries. This study will discuss the electric car batteries issue and, with the help of expert judgment, by using integrated AHP-COPRAS, one of the multi-criteria decision-making approaches, to select the best battery type.

2. MATERIAL AND METHODS

The battery type and attributes were analyzed using the AHP approach in this study, and a decision-making study was conducted. First and foremost, battery factors influencing battery selection were investigated for this aim. Nominal voltage, energy density, volumetric energy density, specific power, life cycle, and operating temperature are some of these properties [42]. In light of this knowledge, our decision-making criteria will be based on nominal voltage, energy density, volumetric energy density specific power, life cycle, operating temperature, and production cost, all of which are debatable for all battery kinds.

This section evaluates AHP by comparing different criteria and battery types based on expert assessments. A total of seven specialists were interviewed bilaterally. Two of the specialists are engineers who are industry professionals in their professions, and five of them are academics.

Analytical Hierarchy Process (AHP)

Thomas L. Saaty created the Analytical Hierarchy Process (AHP), a multi-criteria decision-making technique, in 1971 [43]. AHP; It is made out of previously understood discrete ideas and methods such as pairwise comparison, eigenvector-based weight derivation, and consistency measurement. Every element at every level is put through a two-way comparison with a target element [44]. When distributing weights, AHP has the option of allowing a hierarchical structure of criteria, which enables users to better concentrate on certain (primary) criteria and sub-criteria. A different construction might result in a different final ordering, thus this step is crucial. The decision maker should attempt to cluster these items similarly when building the AHP hierarchy with a lot of them [45].

The Analytical Hierarchy Process (AHP) is used in this study to assign weights to criteria. Figure 1 displays the battery type selection hierarchy framework, and Table 1 lists the importance scale values along with their related meanings.

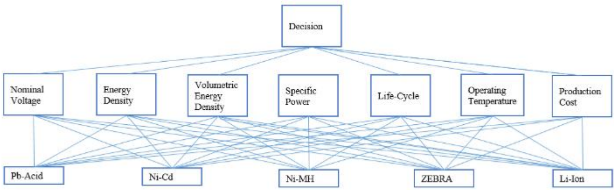

Figure 1. A hierarchical framework for selecting batteries.

Table 1. Importance scale values and definitions [44]

	Intensity of importance	
Saaty 1-9 Scale	1	Equal Importance (EI)
	3	Moderate Importance (MI)
	5	Strong Importance (SI)
	7	Very Strong Importance (VSI)
	9	Extreme Importance (EI)
	2, 4, 6, 8	Intermediate values

The calculation of AHP involved utilizing the following mathematical formula. Specifically, formula 1 was applied to the components listed below the diagonal [46].

$$A=\begin{bmatrix} a_{12} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ \cdots & . & . & . & . \\ \cdots & . & . & . & . \\ a_{n1} & a_{n2} & . & \cdots & a_{nn} \end{bmatrix} \qquad a_{ji}=\frac{1}{a_{ji}} \tag{1}$$

The matrix is created using the normalizing technique to evaluate the significance levels of the components, with a particular emphasis on equation 2 [47].

$$B_i=\begin{bmatrix} b_{11} \\ b_{21} \\ .. \\ .. \\ b_{n1} \end{bmatrix} \qquad bi_j=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

Following that, matrix C is created by combining a collection of B-column vectors in a matrix structure, equal to the number of components. The Priority Vector, which displays the significance values, is then utilized to calculate the mathematical mean of matrix C's row components [44].

The number of elements and a coefficient (λ) known as Eigen Value is used to determine the Consistency Ratio (CR). To acquire the D column vector, initially compare the comparison matrix A with the priority vector W.

$$C=\begin{bmatrix} c_{11} & c_{12} & .. & .. & c_{1n} \\ c_{21} & c_{22} & .. & .. & c_{2n} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ c_{n1} & c_{n2} & .. & .. & c_{nn} \end{bmatrix} \quad W=\begin{bmatrix} W_1 \\ W_2 \\ .. \\ .. \\ W_n \end{bmatrix} \quad W_i=\frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3}$$

$$D=\begin{bmatrix} a_{11} & a_{12} & .. & .. & a_{1n} \\ a_{21} & a_{22} & .. & .. & a_{2n} \\ .. & .. & .. & .. & \cdots \\ .. & .. & .. & .. & .. \\ a_{n1} & a_{n2} & \cdots & .. & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ .. \\ . \\ w_n \end{bmatrix} \tag{4}$$

Equation (5) is used to calculate E, and the arithmetic mean value (equation 6) yields the eigenvalue λ.

$$E_i=\frac{d_i}{w_i} \qquad (i=1,2,\ldots.n) \tag{5}$$

$$\lambda=\frac{\sum_{i=1}^{n} E_i}{n} \tag{6}$$

After calculating the λ, it becomes possible to determine the Consistency Indicator (CI) using equation 7. In addition, the Consistency Ratio (CR) may be derived by dividing the calculated value by the equation (8) and comparing the CI value to the Random Consistency Index (RI) in Table 2.

$$CI=\frac{\lambda-n}{n-1} \tag{7}$$

$$CR=\frac{CI}{RI} \tag{8}$$

Table 2. Values for the random consistency index [48]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency test is considered complete after the CR is determined. The obtained data is consistent if the CR is less than 10%, showing that the comparison matrix is reliable. If the CR is equal to or more than 10%, the collected data is erratic, and the comparison matrix should be altered [19].

Table 3 was generated using experimental numbers from the literature for five distinct battery types.

Table 3. Comparison of Battery Types [49-55]

Battery Property	Pb-Acid	Ni-Cd	NiMH	ZEBRA	Li-Ion
Nominal Voltage (V)	2.0	1.2	1.2	2.6	3.6
Energy Density (MJ/L)	0.36	1.08	1.55	0.32-0.43	0.83-3.6
Volumetric energy density (Wh L^{-1})	100	300	180-220	160	200-400
Specific Power (W kg^{-1})	180	200	200-300	155	200-430
Life-Cycle	1000	2000	<3000	>1200	2000
Operating Temperature (°C)	-15 to +50	-20 to +50	-20 to +60	+245 to +350	-20 to +60

Tablo 4. Experts' response to the one-on-one interview

Decision Variables	*Experts*	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
Nominal voltage C1	***E1***	1	1/3	1/5	1/3	1/7	1	1/3
	E2	1	1/5	1/5	1/5	1/2	1	1/2
	E3	1	1/5	1/7	1/5	1/7	/3	1/9
	E4	1	1/5	1/5	1/7	1/7	/3	1/7
	E5	1	1/3	1/3	1	1/3	1	1/3
	E6	1	1/3	1/7	1/3	1/2	1	1/9
	E7	1	1/5	1/7	1/5	1/7	/3	1/9
Energy Density C2	***E1***	3	1	1	1/3	1/5	3	1/3
	E2	5	1	1	1	1/2	1	1/2
	E3	5	1	1	1	1/3	3	1/5
	E4	5	1	1	1/3	1/3	3	1/5
	E5	3	1	1/3	1	1/3	3	1/3
	E6	3	1	1/7	1/3	3	1	1/9
	E7	5	1	1/3	1	1/3	3	1/5
Volumetric Energy Density C3	***E1***	5	1	1	1	1/3	3	1/3
	E2	5	1	1	1	1/2	1	1/2
	E3	7	3	1	1	1/3	3	1/5
	E4	5	1	1	1/3	1/3	3	1/5
	E5	3	3	1	3	1/2	3	1/2
	E6	7	7	1	1	3	3	1/7
	E7	7	3	1	1	1/3	3	1/5
Specific Power C4	***E1***	3	3	1	1	1/3	5	1/3
	E2	5	1	1	1	1/2	1	1/2
	E3	5	1	1	1	1/3	3	1/5
	E4	7	3	3	1	1	5	1
	E5	1	1	1/3	1	1/2	2	1/2
	E6	3	3	1	1	3	3	1/7
	E7	5	1	1	1	1/3	3	1/5
Life-cycle C5	***E1***	7	5	3	3	1	5	1/3
	E2	7	2	2	2	1	2	2
	E3	7	3	3	3	1	5	1/3
	E4	7	3	3	1	1	7	1
	E5	3	3	2	2	1	2	1/2
	E6	2	1/3	1/3	1/3	1	2	1/9
	E7	7	3	3	3	1	5	1/3
Operating Temperature C6	***E1***	1	1/3	1/3	1/5	1/5	1	1/5
	E2	3	1	1	1	1/2	1	1/3
	E3	3	1/3	1/3	1/3	1/5	1	1/7
	E4	3	1/3	1/3	1/5	1/7	1	1/7
	E5	1	1/3	1/3	1/2	1/2	1	1/3
	E6	1	1	1/3	1/3	1/2	1	1/9
	E7	3	1/3	1/3	1/3	1	1	1/7
Production cost C7	***E1***	3	3	3	3	3	5	1
	E2	7	2	2	2	1/2	3	1
	E3	9	5	5	5	3	7	1
	E4	7	3	5	1	1	7	1
	E5	3	3	2	2	2	3	1
	E6	9	9	7	7	9	9	1
	E7	9	5	5	5	3	7	1

Table 5. Decision Matrix for criteria

Decision Variables	C1	C2	C3	C4	C5	C6	C7
C1	1.0000	0.2489	0.1863	0.2776	0.2306	0.6245	0.1954
C2	4.0169	1.0000	0.5533	0.6245	0.4494	2.1918	0.2425
C3	5.3691	2.1145	1.0000	1.0000	0.5123	2.5643	0.2664
C4	3.6025	1.6013	1.0000	1.0000	0.5993	2.8002	0.3353
C5	5.1857	2.2250	1.9520	1.6685	1.0000	3.5424	0.4562
C6	1.8734	0.4562	0.3900	0.3571	0.3553	1.0000	0.1842
C7	6.1198	3.8328	3.7537	2.9827	2.1918	5.4285	1.0000

Table 6. Normalized matrix for criteria

Decision Variables	C1	C2	C3	C4	C5	C6	C7
C1	0.0368	0.0217	0.0211	0.0351	0.0432	0.0344	0.0729
C2	0.1479	0.0871	0.0626	0.0789	0.0842	0.1207	0.0905
C3	0.1976	0.1842	0.1132	0.1264	0.0960	0.1413	0.0994
C4	0.1326	0.1395	0.1132	0.1264	0.1123	0.1543	0.1251
C5	0.1909	0.1938	0.2209	0.2109	0.1873	0.1952	0.1702
C6	0.0690	0.0397	0.0441	0.0451	0.0665	0.0551	0.0687
C7	0.2253	0.3339	0.4249	0.3771	0.4105	0.2991	0.3731

COPRAS method

Zavadskas and Kaklauskas presented the COmplex Proportional ASsessment approach to the literature in 1996 [56]. It is used to rank and assess options while taking the benefit and cost features of the criterion into account [14]. The distinction between this approach and other MCDM methods is that the options may be compared to each other and their superiority over each other can be expressed as a percentage. The application of this method is as follows

i. Decion matrix created

$$A_{ij} = \begin{matrix} a_{11} & \cdots & a_{1p} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mp} \end{matrix}$$

where m is alternative and p is criteria

ii. The elements of matrix A are used to compute the normalized decision matrix (X*). The elements of the normalized resolution matrix are represented by (x_{ij}^*). Equation (9) was implemented to calculate (x_{ij}^*).

$$x_{ij}^* = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (9)$$

$$(i = 1, \ldots, m \text{ and } j = 1, \ldots p)$$

$$X^* = \begin{matrix} x_{11}^* & \cdots & x_{1p}^* \\ \vdots & \ddots & \vdots \\ x_{m1}^* & \cdots & x_{mn}^* \end{matrix}$$

iii. The weighting of the normalized decision matrix is determined using equation 10 and the weights w_i.

$$n_{ij} = x_{ij}^* w_j \quad (10)$$

iv. S_i^+ and S_i^- values calculated

S_i^+ the sum of utility criteria in a weighted normalized decision matrix

S_i^- the sum of cost criteria in a weighted normalized decision matrix

v. Equation 11 is used to compute relative significance values.

$$Q_i = S_i^+ + \frac{\sum_{i=1}^{m} S_i^-}{S_i^- \sum_{i=1}^{m}\left(\frac{1}{S_i^-}\right)} \quad (11)$$

vi. Equation 12 is used to calculate the value of the performance index.

$$P_i = \left(\frac{Q_i}{Q_{max}}\right) * 100 \quad (12)$$

3. RESULT AND DISCUSSION

Seven experts were interviewed one-on-one and questions were posed Table 4 has been prepared. By taking the geometric mean of the values given in Table 4, the decision matrix (Table 5) was generated.

In order to normalize the decision matrix (table 5) equation 2 was used. Results tabulated in Table 6.

Once the normalization was completed, the eigenvector, eigenvalue, consistency index and consistency ratio were determined by using equations 3 to 8. The results were tabulated in Table 7.

The CR is less than 10%, implying that the data acquired is consistent, demonstrating that the matrix used for comparison is reliable. The weighted outcomes of the criterion calculations are tabulated in Table 8.

where wC1: weight of Nominal voltage, wC2: weight of Energy Density, wC3: weight of Volumetric Energy Density, wC4: weight of Specific Power, wC5: weight of Life-cycle, wC6: weight of Operating Temperature, wC7: weight of Production cost

Ranking the batteries with COPRAS

After the weights are determined by AHP, a ranking will be made between the alternatives with the COPRAS method. To appeal to the consumer (buyer), the manufacturing cost requirement was also added, and expert opinions were sought.

In addition to the values given in the literature, linguistic evaluation such as expensive, very expensive, given verbally, is given a 1 to 9 scale to be close to the Saaty scale.

Table 7. The results of the eigenvector, eigenvalue, consistency index and consistency ratio

eigen vector	*eigenvalue*	*λmax*	*CI*	*CR*
0.037884	0.271082	7.30908	0.0515	0.0382
0.095996	0.698679			
0.136866	1.007783			
0.129048	0.945755			
0.195612	1.443963			
0.05548	0.403517			
0.349114	2.577456			

Table 8. Weight of the criteria

w_{C1}	w_{C2}	w_{C3}	w_{C4}	w_{C5}	w_{C6}	w_{C7}
0.0379	0.0960	0.1369	0.1291	0.1956	0.0555	0.3491

Table 9. Production cost

	Pb-Acid	**Ni-Cd**	**NiMH**	**ZEBRA**	**Li-Ion**
Production Cost	Cheap	Over costing	Over costing	Average	Over costing

Table 10. Linguistic Scale

Linguistic	**Scale**
Very Cheap	1
Cheap	3
Average	5
Expensive	7
Very Expensive	9

To evaluate the batteries the chosen criteria are coded as: *C_1: Nominal voltage criteria, C_2: Energy Density criteria, C_3: Volumetric Energy Density, C_4: Specific Power criteria, C_5: Life-cycle criteria, C_6: Operating Temperature criteria, C_7: Production cost criteria*

The decision matrix was created using literature [49-55]. The alternatives of batteries were symbolized as Pb-Acid: A1, Ni-Cd: A2, Ni-Mh: A3, Zebra: A4, and Li-ion: A5, respectively. While creating the decision matrix operating temperature is given as a range so the maximum temperature is chosen for evaluation since it is considered a utility. In addition to this assumption, Life-cycle criteria were given for the battery Ni-Mh as <3000 and also for the ZEBRA type battery >1200 these values were taken as 2900 and 1300, respectively.

Table 11. Decision matrix for evaluating alternative batteries

Alternatives	*Criteria*						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	2	35	100	180	1000	50	3
A_2	1.2	80	300	200	2000	50	9
A_3	1.2	95	220	300	2900	60	9
A_4	2.6	120	160	155	1300	350	5
A_5	3.6	250	400	430	2000	60	9

In order to normalize the decision matrix (Table 11) equation 9 was used and the results were tabulated in Table 12.

The weight of the criteria that were calculated by the AHP method was used to calculate the weighted normalized matrix by using equation 10 and the results are tabulated in Table 13.

Table 12. Normalized matrix for alternative batteries

C_1	C_2	C_3	C_4	C_5	C_6	C_7
0.1887	0.0603	0.0847	0.1423	0.1087	0.0877	0.0857
0.1132	0.1379	0.2542	0.1581	0.2174	0.0877	0.2571
0.1132	0.1638	0.1864	0.2372	0.3152	0.1053	0.2571
0.2453	0.2069	0.1356	0.1225	0.1413	0.6140	0.1429
0.3396	0.4310	0.3390	0.3399	0.2174	0.1053	0.2571

Table 13. Weighted normalized matrix

C_1	C_2	C_3	C_4	C_5	C_6	C_7
0.0071	0.0058	0.0116	0.0184	0.0213	0.0049	0.0299
0.0043	0.0132	0.0348	0.0204	0.0425	0.0049	0.0898
0.0043	0.0157	0.0255	0.0306	0.0617	0.0058	0.0898
0.0093	0.0199	0.0186	0.0158	0.0276	0.0341	0.0499
0.0129	0.0414	0.0464	0.0439	0.0425	0.0058	0.0898

The criterion C1 to C6 are utility criteria and C7 is the cost criteria. Si+ and Si- values are calculated where Si+ the sum of utility criteria in a weighted normalized decision matrix and Si- the sum of cost criteria in a weighted normalized decision matrix. Si+ and Si- values were used to compute the relative significance values. Equation 11 is used to compute relative significance values (Qi). And the gained results are tabulated in Table 14.

Table 14. Relative Significance values of the alternatives

Alternative	S_i^+	S_i^-	$1/S_i^-$	Q_i
A_1	0.0690	0.0299	33.4183	0.2033
A_2	0.1201	0.0898	11.1394	0.1649
A_3	0.1436	0.0898	11.1394	0.1884
A_4	0.1252	0.0499	20.0510	0.2058
A_5	0.1929	0.0898	11.1394	0.2376

Relative significance values were used to calculate the performance indices. Performance indices were calculated by using Equation 12 and the computed results are tabulated in Table 15. The performance index shows the ranks of alternatives.

Table 15. Performance index

	Performance index
P_1	85.5551
P_2	69.3848
P_3	79.2800
P_4	86.6036
P_5	100.00

Table 16. Ranks of batteries

Alternative	*Performance index*	*Rank*
A_1	*85.5551*	*3*
A_2	*69.3848*	*5*
A_3	*79.2800*	*4*
A_4	*86.6036*	*2*
A_5	*100*	*1*

Once the performance index is calculated the ranks of the alternatives which are tabulated in Table 16 come to the fore.

where A_1: Pb-Acid, A_2: Ni-Cd, A_3:Ni-Mh, A_4: Zebra, A_5: Li-ion, respectively.

The calculations show that alternative A5, with the highest performance index, is the best option, while alternative A2, with the lowest performance index, is the worst. In terms of battery preferences, the final ranking is as follows: Li-ion, Zebra, Pb-Acid, Ni-Mh, and Ni-Cd, in that order. A decision has been made to encourage the development and deployment of alternative Li-ion, which has the greatest performance index.

4. CONCLUSION

The environmental damage of internal combustion engines threatens the balance of the world. For this reason, scientists have started to search for renewable alternative vehicles in terms of environmental impact and health. Electric vehicles have grown in popularity among researchers because they are safe, ecologically benign, and long-lasting.

The analytical hierarchy technique was used to examine the properties of five distinct battery types (Pb-Acid, Ni-Cd, NiMH, ZEBRA, and Li-Ion) in this study. The present study examined seven distinct battery properties (nominal voltage, energy density, volumetric energy density, specific power, life cycle, operating temperature, and production cost) and five different battery types. The relevance of attributes is given as manufacturing cost, life-cycle, volumetric energy density, specific power, energy density, operating temperature, and nominal voltage, according to determined weighted results using AHP. Based on this point, the COPRAS method assessment of five distinct battery types revealed that Li-Ion is the best-suited battery type and Ni-Cd is the least favorable among the analyzed battery kinds. In prospective research, different attributes and battery kinds can be produced. Similarly, the outcomes may be compared using various multi-criteria decision-making procedures.

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CRediT authorship contribution statement

Aslı Abdulvahitoğlu: Conceptualization, Formal Analysis, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Gözde Ekmekçi Güçlüten:** Investigation, Resurces, Writing - Original Draft

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