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Multicriteria decision making and goal programming for determination of electric automobile aimed at sustainable green environment: a case study

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Abstract
In this paper, we consider the problem of automobile selection for transportation in inner city using a hybrid multicriteria decision making approach. The electric automobiles that are a relatively new concept in the world of the automotive industry, are widely viewed as attractive among its alternatives day by day. Fuel-vehicles produce a lot of carbon emissions that are ejected into our natural atmosphere, leaving us vulnerable to things like pollution and greenhouse gases. So, electric vehicle and automobiles have emerged as a more efficient alternative and these vehicles have been a great step forward to help positively the environment with zero emissions and total energy consumption in their lifecycle. Many companies focus on electric vehicle production with the development of electric vehicle technology. Therefore, the selection process emerges among the various electric automobile technologies for the users. The selection process includes several conflicting factors which are such as economic, technical and technological factors. In the present study, we propose a hybrid approach for electric automobile selection that combines analytic hierarchy process (AHP), technique for order of preference by similarity to ideal solution (TOPSIS) and goal programming (GP) is used to determine the weights to assign to the factors that go into these selection decisions and TOPSIS method is used for preference ranking. These weights founded by AHP are inputted into a GP model to determine the best alternative among the electric automobiles. Finally, the study used three methods TOPSIS, AHP- TOPSIS and AHP-GP for better comparison and evaluation. The most suitable electric automobile is selected among their alternatives by using analytic methods and goal programming.

Keywords Electric automobile selection · AHP · TOPSIS · Goal programming · Sustainable green environment

1 Introduction

In recent years, population is increase day by day in cities. In 2014, around 54% of the world's population lived in urban areas. If this trend continues, around 66% of the world's population, which represents 6 billion people, will be living in urban areas by 2050 (United Nations 2014). This situation has been lead to the rapid growth of private car use in urban areas and puts higher pressure on the urban transportation system. Many cities in worldwide meet face to face these problems with the rapid growth of population and the high level of dependence on private motor vehicles. Especially air pollution is a serious problem for human health and the environment, and this is one of the most important subjects that is need an immediately solution (Mabahwi et al, 2014). Thence, many cities have experienced serious problems of air quality with the fast-paced urban growth. Besides, global warming, largely caused by the heavy use of fuel vehicles in road transport, is becoming a major environmental issue in the world (Rahimi and Davoudi, 2018). Thus, It is important to seek out effective solutions to minimize their adverse effects on the urban environment. Policymakers around the world are currently make studies to solution environmental problems. They are aimed with these studies to reduce the impact of the air-pollution and use of the consumption of fossil fuel resources (Sim et al., 2014). So, the urban transportation is a major problem for sustainable development in terms of fossil fuel usage and carbon dioxide emissions

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for city centers. Scientists, city planners and policymakers research different options to cope with all these problems. These solutions include the improvement of city planning and infrastructure to reduce congestion; the development of a new generation of private motor vehicles with less detrimental emissions; establishment of travel behaviour change programs intended for active transport; and provision of alternatives to private car use (Loukopoulos, 2007). In addition to, the use of electric vehicles (EVs), hydrogen vehicles, public transport or the promotion of cycling are between these options (Mashayekh et al., 2012; Eberle and von Helmolt, 2010a, 2010b; Offer et al., 2010).

Although alternative technologies are crucial to reduce environmental effect with urban transport, oil-based vehicles still account for the largest share of the transportation in many cities. To deal with these problems, supporting the clean technology has become the consensus of the whole society and EVs play an effective role in the low-carbon transition (Daramy-Williams et al., 2019). Meanwhile, limited fuel in the world is another reason to persuade the decision makers to usage of EVs. In this point, the process of conversion to EVs from fuel- vehicles is more important for sustainable cities due to resource scarcity, reduce greenhouse gas (GHG) emissions and negative environmental impacts. Therefore, as clean energy, EVs are drawing more attention under dual pressure of limited fuel and pollution for the usage in urban areas.

EVs use the energy stored in a battery (or series of batteries) for vehicle propulsion. Electric motors provide a clean and safe alternative to the internal combustion engine. EVs help a greatly contribute towards a healthy and stable environment. Briefly, to reduce the dependence on oil and environmental pollution, the development of EVs has been accelerated in many countries. Due to all these problems and the increasing number of internal-combustion vehicles, many countries have implemented new energy vehicles as alternatives to conventional vehicles. In parallel to recent advancements around the world, many countries have been spending efforts to promote the use of clean technologies. Besides, for this reason, many countries have adopted numerous laws and regulations related to the substantial reduction of pollutant emissions caused by transportation using internal combustion engines as an energy source. Especially, China as the world's largest automotive market and the huge population; many countries in Europe and ABD with the largest economy. So, many countries in the world have accelerated the transformation to clean technology vehicles (Li, 2019; Wenbo et al., 2016; Hu et al., 2018). Moreover, Germany promote to have one million EVs to reduce CO2 emissions (Gong et al., 2013; Bubeck et al., 2016; Massiani, 2015). France and UK have also aimed to restrict the in-country sale of conventional vehicles by 2040. US, Japan, Chine have been implemented to special tax policies for the green vehicle purchasing promotion measures (Palmer et al., 2018).

Over the past years, EVs has gained increasing attention by policymakers and consumers, especially due to their potential to reduce GHG emissions (Ellingsen et al., 2016). Thus, electric vehicle market has been shown significant growth in today. Many Famous manufacturers such as Volkswagen, Mercedes, and Ford etc. have converted to electrical concept the vehicle portfolio of themself. There are many electric vehicle models and firms that are present in market with different combinations. So, many car manufacturers have started to the development studies on EVs for better performance and this process continues rapidly.

However, EVs have some disadvantage, existing limitations and difference to each other such as limited driving ranges, insufficient chargers, long recharging duration and upfront purchasing cost (Amirhosseini and Hosseini, 2018; Langbroek et al., 2019). These differences show varies according to automobile company and automobile types. Besides, EVs make a significant contribution sustainability in terms of environmental effect in cities. To do this, EVs as cleaner technology should be supported by decision makers, and all society. Nevertheless, to the authors' knowledge, there has been very little work on decision making with analytic processes for the selection of electric automobile for transportation. While technical aspects are very relevant for the successful introduction of these new vehicles, to decide for the best automobile among alternatives need multi-criteria evaluation process.

When a customer needs to acquire a new electric automobile or automobile for its daily life, many factors must be taken into account. This requires a good command of conflicting factors, which can benefit from the domain of Multi-Criteria Decision Making (MCDM). There are various factors which affect the performance of an electric vehicle such as battery capacity, charging time, price, driving range etc. All these factors are improved further by manufacturers day by day. So, the electric vehicle (EV) technology has been getting momentum rapidly every passing day. These differences and limitations of EVs have been necessitated the decision-making process for purchase preferences of customers. In addition, we will find the answer to the question of which vehicle is the most suitable or optimal with this study, we will help to customers for their purchase preference with analytic and optimization models.

The effective selection of electric automobile for multiple criteria types is essential for the sustainable practice of transportation. Thereby, MCDM tools are very useful method for decision making for selection process. Besides, when the problem has got constraints and goal values, mathematical models such as GP give optimal results. Moreover, MCDM tools and mathematical models can use with together. Various studies have deal with the electric vehicle selection in which some innovative approaches have been utilized previously in the literature. Due to that fact, the combination of MCDM methodologies with techniques such as ranking methods-TOPSIS, selection model-goal programming provides a very useful decision process of dealing with the optimum selection.

1.1 Organization

In this article, Electric vehicle selection is made by using MCDM methods and mathematical modelling, and solution results are analysed as well. The rest of this article is organized as follows: Literature about EVs and their consumer preferences are presented in more detail in Sect. 2, while in Sect. 3 the AHP, TOPSIS and GP, analytic methods are briefly provided. There are mention about usage of electric vehicles and electric vehicles in Turkey in the Sect. 4. Case study under the ten alternative vehicles and specific evaluation criteria is presented in Sect. 5. Results of application (AHP-TOPSIS and AHP-GP) are presented and sensitive analyses are discussed in Sect. 6. Finally, study conclusions are given in Sect. 7.

2 Literature review

A review of the specialized literature shows that clean-technology vehicles have been the focus of air quality, sustainability, and development of more liveable cities. Studies on the preference of costumer, sales values, marketing, and consumer behaviour analyse in clean technology-vehicles have been carried out by many researchers. Besides, the huge contributions have ensured at decision making literature with some studies done using MCDM. The literature provides many examples of MCDM applications in the transportation field (Mardani et al., 2016) and, their combination with other MCDM methods are also being analysed in recent decades. Researchers have used various methods to selection process for transportation, such as AHP (Osorio-Tejada et al., 2017; Tsita and Pilavachi, 2012, 2013); ANP (Sayyadi and Awasthi, 2020); TOPSIS (Oztaysi et al., 2017; Büyükozkan et al., 2018; Mukherjee, 2017; Onat et al., 2016); VIKOR (Ren et al., 2015; Aydın and Kahraman, 2014); PROMETHEE (Sehatpour et al., 2017; Ziolkowska, 2013, 2014; Turcksin et al., 2011); ELECTRE (Cai et al., 2017); MOORA (Hamurcu and Eren, 2020a, b, c); fuzzy applications (Mukherjee, 2017; Ziolkowska, 2014; Ren and Lützen, 2015; Vahdani et al., 2011); hybrid MCDM applications (Büyükozkan et al., 2018; Aydın and Kahraman, 2014) and optimization applications (Ziolkowska, 2013; Traut et al., 2012; Hamurcu and Eren, 2018). Consequently, deal with alternative fuels, studies showed that there is a rising interest in sustainable means of transport, such as EVs or cleaner technologies.

With growing attention towards alternative technologies, one should also consider clean technologies, which is a popular subject in many research area (Khan et al., 2022; Kakoti et al., 2022; Dutta et al., 2020; Prasad et al, 2019). Clean technologies that is a popular subject, have growing attention in many areas (Erzurumlu and Erzurumlu, 2013; Mizik and Gyarmati, 2021). Many authors offered EVs for transportation and more liveable environment (Aujla et al., 2019; Srivastava et al., 2022; Hamurcu and Eren, 2020a, b, c). Many papers presented said that this area needs more development. (Hamurcu and Eren, 2020a, b, c). Besides, studies have shown that clean technology vehicles, highly demanded by many cities and people, are tending to be more preference (Ghasri et al., 2019; Lane et al., 2018; Secinaro et al., 2022).

Literature presents some transportation studies which combine MCDM methodologies and AHP. With reference to that literature, it should be noted that the use of the AHP in its MCDM and GP is very widespread. In this section, consumer prefers and EVs and literature review conclusion are researched under the four sub-titles.

2.1 Consumer preferences

When we evaluate in terms of electric vehicle consumers, we attain various result in the existing literature research on consumer behaviours. In the literature, the consumers' preferences and behaviour for EVs has been studied at the resent years. For example, Liu et al. (2017) researched the factors that influence the diffusion of EVs in China using MCDM methods. Used evaluation dimensions in their study are industry and production systems, vehicle-related factors, markets and user practices, symbolic meaning, infrastructure and urban planning, policy-related factors and external factors and they used 21 factors dependent of these dimensions. According to their results, key factors influencing the diffusion of EVs was mentioned as technological level, policies and regulations, consumer acceptance and expectation, price and models, and market structure and competition.

Liao et al. (2017) presented a comprehensive review about consumer preferences. They evaluated from different perspectives consumer preferences, according to economic and psychological approach, modelling techniques applied, financial, technical, infrastructure and policy attributes. The study examined that electric vehicle preference studies generally include the financial, technical, infrastructure and policy attributes. The study mentioned to important factors in terms of financial, technical and infrastructure attributes that are purchase price, operation cost, driving range, charging time, engine power, acceleration time, maximum speed, CO2 emission, brand, brand diversity, warranty, charging availability. Besides, they also gave an overview of their finding about policy attributes that are another an important factor of preference, such as pricing policies, reduce purchase price, free parking, reduce toll, land-use policy. In addition to these finding, they mentioned that socio-economic and demographic characteristics are the categories of individual-related variables (example. gender, age, income, education level and household composition etc.) most often included in choice studies.

Ma et al. (2019) analysed online behaviours of consumers' preferences for EVs. In regulated summary table in their study briefly mentioned the most important effect factors on EVs utilizing from studies of Higgins et al. (2017); Du et al. (2016); Safari (2018); Fetene et al. (2017); Hidrue et al. (2011); Tanaka et al. (2014); Hidrue et al. (2011); Langbroek et al. (2016); Lane et al. (2018); Massiani (2015); Mohamed et al. (2018) Plötz et al. (2014); Fetene et al.(2017);Helveston et al. (2015) that are size, battery, charge, range, powertrain type, classification, fuel economy and brand.

Guo et al. (2020) limited the electric vehicle preference factors in four categories as the policy instruments, operational costs, demographic variables, and psychological determinants. Determined these categories consist of respectively sub-factors following, subsidies and charging discount, taxes, license controlling, and public procurement; total cost, purchase cost, trip cost, maintenance cost and energy price; gender, age, education, household size, and family income, personal preference, and perception, self-efficacy and response efficacy, and environmental awareness.

Wang et al. (2020) analysed to the intentions of purchase of new energy vehicles of consumers. In research is analysed published total 1000 papers in the Web of Science during the period 2013–19. In the results of the analyse are gathered seven large feature that are vehicle itself (small features: appearance, cost performance, trim, power, space, endurance, configuration, manipulation, consumption, and brand), national policy (license restrictions, subsidies, purchase tax, and loan), demographic (region, social relationship, and occupation), infrastructure (electric piles and parking lots), battery technology, safety awareness, and environmental awareness. It has been shown that policies, infrastructure, demographic factors, and safety awareness are closely related national with the sales volume in results of the statistical analyses done with deep-learning technologies and data mining. In addition, this result, it found that primary motivating factors of purchase reasons are the vehicle, demographic characteristics, and national policy.

Key success factors of consumer's preference of new energy vehicles include energy consumption, energy price, the amount of energy supply stations, national subsidies, national policy, driving skills, and carbon dioxide emissions (Zhang et al., 2018a, 2018b; He et al., 2017; Gnann et al., 2015; Hardman et al., 2018; Yu et al., 2016; Lin and Wu, 2018; Jensen and Mabit, 2017; Li et al., 2018).

In addition to, many researchers have studied and identified factors influencing the preference factors of EVs. The main factors are purchase price (Ma et al., 2019b; Chen et al., 2019a, b; Huang and Qian, 2018; Lin and Wu, 2018); size (Higgins et al., 2017); power type (Lane et al., 2018); Ma et al., 2019b); vehicle classification (Mohamed et al., 2018; Ma et al., 2019b); fuel economy (Fetene et al., 2017); operation cost (Valeri and Danielis, 2015); driving range (Paul Helveston et al., 2015; Huang and Qian, 2018); charging time (Fetene et al., 2017); charging availability (Huang and Qian, 2018; Wang et al., 2017); acceleration time (Paul Helveston et al., 2015); environmental friendly (Wang et al., 2017; He et al., 2018; Lin and Wu, 2018; Wang et al., 2017; Zhang et al., 2018b); brand (Ma et al., 2019b; Wang et al., 2017); appearance (Ma et al., 2019b) and policy (Chen et al., 2019a, b; Huang and Qian, 2018; Paul Helveston et al., 2015; Lin and Wu, 2018; Ma et al., 2019a).

Besides, psychological and demographic levels, personal needs, personal behaviour, psychological needs and personal characteristic also are important factors in the preference of NEVs (Li et al., 2017; Zhang et al., 2013; Axsen et al., 2015, 2009; Morton et al., 2016; He et al., 2018).

While there are many studies about researches of consumer preferences of EVs in prior studies, literature is limited about the selection of electric vehicle or automobile by using multicriteria decision making. So, this study present, analytic methodology, a selection process based on criteria used in consumer preferences. We will be ensuring a support for literature using decision making process with this study.

2.2 Recent studies in the selection of electric vehicles by using MCDM

Although electric vehicle technology has advantage such as being eco-friendly, quieter operation, lower fuel and maintenance costs, better acceleration, and higher energy efficiency (De Clerck et al., 2018; Zivin et al., 2014), have some disadvantages. These disadvantages are especially being more expensive, shorter range, longer charging time, insufficient battery capacity, and inadequate infrastructure. These features must be improving for electric vehicle dissipation. This is a bigger problem for countries that have not yet completed their infrastructure. Therefore, the installation of the infrastructure independent of the vehicle as well as the features of the electric vehicle is one of the most important factors for the dissipation of the EVs. Many researchers are also working on the installation of the electric vehicle infrastructure (Huang and Kockelman, 2020; Kabli et al., 2020; Lin et al., 2020).

There are some studies in literature about selection of electric vehicle technology using MCDM. The last literature is shown in Table 1. Khan et al. (2020) done the selection among the seven commercially available hybrid electric vehicle by using MCDM method. Ten evaluation criteria under the main criteria that are economic, environmental, social perspective have been taken into consideration in their study. Sub-criteria are purchasing cost, maintenance cost, and registration cost, fuel economy, hybrid battery's life the comfort of the car and its reliability, GHG emissions, employment opportunities, safety features, and status symbol.

In addition to, various classic fuel-vehicle technologies in various areas also are considered to select the most sustainable for customers using MCDM in the literature; terrain vehicle selection (Starčević et al., 2019), luxury car selection (Apak et al., 2012), selecting an automobile purchase model (Byun, 2001), car selection (Singh and Avikal, 2019), evaluation of two wheeler automobiles (Yogi, 2018),application on automobile sector (Tunçel et al., 2017), selection of ambulance supplier company (Alakaş et al., 2019).

Most of researchers analyzed MCDM methods for selection process and proposed various decision-making models for improvement of urban transportation and decision-making processes. In these studies, done various papers to improve urban transportation, to select the best alternative using decision making methods, AHP, TOPSIS, MOORA, VIKOR, PROMETHEE CRITIC-CoCoSo about hybrid electric vehicle (Iç and Şimşek, 2019; Khan et al., 2020); commercially EVs (Biswas and Das, 2019; Biswas et al., 2020), electric bus technology (Hamurcu and Eren, 2020a, b, c; Hamurcu and Eren, 2022), alternative vehicle technology selection (Al-Alawi and Coker, 2018; Büyüközkan et al., 2018), clean energy vehicles technologies (Li et al., 2019), and determinaton of materials for sustainable manufacturing in automotive industry (Stoycheva et al., 2018).

2.3 Literature review conclusion

We do not met study an established model under the constraint of customer and some technical goals for automobile selection. Although many studies are in selection process about using MCDM, only a few studies deal with comparison between of MCDM and mathematical model results in the literature. Besides, disseminating electric automobiles together with developing technology are an important situation for urban transportation and air quality. Also, Turkey have been developing electric vehicle market. So, decision making has been becoming an important issue to bought new electric automobile. This study also will be help in consumer's preference.

As is seen from the literature, MCDM tools are one of the most popular and effective methods adopted in the automobile selection process because of the advantages of the MCDM. Conflicting and mutiple objectives for automobile selection problems are commonly found in real-life decisions like maximizing the range or full charge time and minimizing the purchasing price. MCDM methodology considers the all od these stuations. Thus, it can be give more advantageous decisions for aotomobile selection in considering

Table 1 Selection of alternative clean technology vehicles

Author/s-(Year)	Vehicle type (Alternatives)	Used MCDM Methods	Journal
Ziemba (2021)	Selection of electric vehicles	Fuzzy TOPSIS; fuzzy SAW; NEAT F-PROMETHEE	Energies
Mumani and Maghableh (2021)	Eco-friendly car selection	ANP-ELECTRE III	Journal of Engineering Research
Ecer (2021)	Performance assessment of battery electric vehicles	MCDM methods	Renewable and Sustainable Energy Reviews
Khan et al. (2020)	Hybrid electric vehicle	Fuzzy TOPSIS	Air Quality, Atmosphere & Health
Hamurcu and Eren (2020a, b, c)	Electric bus technologies	AHP-TOPSIS	Sustainability
Biswas et al. (2020)	Alternative electric vehicles	CRITIC-CoCoSo	Operational Research in Engineering Sciences: Theory and Applications
Hamurcu and Eren (2020b)	Electric bus technologies	MOORA-TOPIS	Transport
Biswas and Das (2019)	Commercially electric vehicles	AHP-MABAC	Journal of The Institution of Engineers (India): Series C
Iç and Şimşek (2019)	Hybrid electrical automobiles	TOPSIS	SN Applied Sciences
Liang et al (2019)	Alternative-fuel based vehicles	Fuzzy AHP-TOPSIS	Technological Forecasting and Social Change
Li et al (2019)	Clean energy vehicles technologies	AHP-VIKOR	Energy Policy
Büyüközkan et al (2018)	Alternative-fuel based vehicles (bus)	MCDM	Transportation Research Part D: Transport and Environment
Al-Alawi and Coker (2018)	Alternative vehicle technology selection	PROMETHEE	Energy

all of these stuations.Moreover, the MCDM methods can presents more evaluation perspectives i n terms of reliability of the final outcome.

Real-life problems provides a set of comprehansive alternatives and many evaluaton criteria effects in decision making process. Thus, providing a set of comprehensive evaluation will be effective and easier for decision making process instead of using automobiles's all tecnical characteristic.

MCDM methods and GP model are used to select the most suitable electric automobile in consideration of the decision problem structure in terms of complexity, conflicting and mutiple goals in this paper.

AHP helps to find evaluation criteria weights. Topsıs method ensure preference rank. GP model provides that the different goals combine in the same model.In real-life problems, evaluation criteria have different important levels. So, AHP-TOPSIS and AHP-GP models use as combine. To identify the solution to the problem, the highest weighted goals and constraints are considered with AHP combin. There are so many improved MCDM methods in the literature for automobile selecion. But optimization models like GP have yet establised. So, this study presents AHP-TOPSIS and AHP-GP hybrid models' comparisions. To the best of our knowledge, no study has presented the AHP-GP approach for electric automobile selection.

2.4 Contributions

This study will contribute to the literature with systematic decision-making approach to the selection of electric automobile that can help the decision of automobile purchase of customers. This study is aimed to the selection of electric automobile by using multiple criteria decision-making tools and mathematical modelling by which customer can have knowledge about specific factors of EVs in decision process of automobile purchasing it. Electric automobile manufacturers can have knowledge about what is the most important factors in automobile preference. The methods used in our study on decision making process are AHP and TOPSIS for rank, and GP for the optimum selection.

One of the basic principles of sustainable engineering, according to Abraham that include environmental, social, and economic factors is minimizing the depletion of the natural resources (Abraham, 2006). So, our study has been presenting a sustainable solution for air quality based on improving natural ecosystems. Besides this study helps decision makers that their decision-making process applying engineering solutions based on the using analytic and mathematical models.

This study will contribute to the literature with systematic an approach to the selection of electric automobile vehicles and will help customers to their decision-making processes. The authors search to answer this question "Which electric automobile is the best for purchasing in recent conditions?" and "Can the GP model more effective for selection process" In this paper, the authors propose a novel AHP-based approach to select the best electric automobile. The key research contributions of the proposed study are as follows:

- To identify the critic criteria, which effect the electric automobile selection
- To develop a hybrid decision-making model to determination of the best electric automobile and select the best electric automobile based on real-life constraints under the different scenarious.
- To demonstrate the working of proposed AHP-GP model with the help of real-time case study
- To compare the results of ranking (AHP-TOPSIS) and optimization (AHP-GP)
- To perform the sensitivity analysis to check the effect of evaluation criteria to check the effect of critria weights on the ranking and selecting of electric automobiles.

3 Analytical methods

There are many MCDM tools supporting techniques to help decisions makers. The most known are AHP, TOPSIS, ELECTRE, PROMOTHEE, VIKOR etc. These techniques in practice can be used separately or hybrid. In this regard, there are many study that argue environmental applications which using by MCDM methods (Linkov et al., 2021). (For more detailed information on decision analysis methods and environmental application can refer to Linkov et al.(2021). In this paper we focus on three techniques: AHP and TOPSIS, and utilizes GP model for third MCDM method. The AHP to determine the weights of criteria, TOPSIS to rank alternatives and GP to select the best alternative are used. A brief description of each method is provided below.

3.1 Analytic hierarchy process (AHP)

The AHP is well known method that has the characteristics of flexibility, ease of use, and simplicity, and it has been extensively applied in planning and development processes for various purposes. The AHP has the easiness of the implementation, which can be completed in three simple steps such as computing the vector of criteria weights, computing the matrix of option scores, and ranking the options (Saaty, 2008). this method based on pairwise comparisons via expert opinions. Pairwise comparisons present a wide perspective to decision makers(Saaty, 1980). The basic steps of the AHP methodology are as follows in Table 2.

3.2 TOPSIS

The TOPSIS method based on the concept of positive ideal solution and negative ideal solution that was proposed by Hwang and Yoon (Hwang and Yoon, 1981), has rational and understandable logic. When its computation processes are considered to straightforward, have been used to many areas for ranking. Besides, other reasons for the widely use of this method are rational, understandable and ease of its computational process, providing the pursuit of best alternatives for each criterion depicted in a simple mathematical formulation. In addition to, the importance weights can incorporate into the comparison procedures. The TOPSIS method is described in the following steps in Table 3 (Hwang & Yoon, 1981):

3.3 Goal Programming

The ZOGP method that does try to contribute suggestions to decision makers for resource allocation and usege, selection processes, was first recommended in 1955 by Charnes and firiends (Charnes et al. 1955). This models are mathematical models. But, results may not provide an optimality. The ZOGP method aims to minimization of deviations between achievement goals and realized results. GP has a wide application in decision analysis particularly where there

Table 2 AHP steps

Steps	Purpose	Formulation	Symbols	Explain
Step 1	Decision matrix	$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$	A: decision matrix a_{ij} : the value of the ith row and jth column	Creating a pair-wise comparison matrix is constituted according to expert interview. In this process, Saaty's 1–9 scale is used to identify the importance levels
Step 2	Established normalize matrix	$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$ $W_i = \frac{\sum_{i=1}^{m} r_{ij}}{n}$	r_{ij}: normalization values W_i: eigenvector/important leves n: the number of criteria	Normalization of the pair-wise comparison matrix is done by using these formulations
Step 3	Consistency checking	$CI = \frac{\lambda_{max}-1}{n-1}$ $CR = \frac{CI}{RI}$	CI: consistency index CR: consistency ratio RI: random index λ_{max}: the average consistency	The CR value is less than 0.1 then it can be accepted that the decision maker judgements are true and consistent

Table 3 TOPSIS steps

Steps	Purpose	Formulation	Symbols	Explain
Step 1	Decision problem and normalization	$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{j} f_{ij}}}$	r_{ij}: Normalization values f_{ij}: The evaluation matrix	
Step 2	The weighted normalization matrix	$W = r_{ij} * w_{ij}$	W: The weighted normalized decision matrix w_{ij}: Criterion weights	The weighted normalization decision matrix is constructed
Step 3	Determination of ideal-negatice ideal solutions	$A^+ = \left\{ \left(\min_i v_{ij} \lvert j \in J \right), \left(\max_i v_{ij} \lvert j \in J' \right) \right\}$ $A^- = \left\{ \left(\max_i v_{ij} \lvert j \in J \right), \left(\min_i v_{ij} \lvert j \in J' \right) \right\}$	A^+: Ideal solution A^-: Negatice ideal solution	
Step 4	Calculation the separation measures: nehative and pozitive separation	$d_{ij}^+ = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^+ \right)^2}$ $d_{ij}^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^- \right)^2}$	d_{ij}^+: The separation of each alternative from the ideal solution d_{ij}^-: The separation of each alternative from the negative ideal solution	Calculate the separation measures under the criteria for each alterntaives
Step 5	Calculation of the relative closeness to the ideal solution	$CC_j^* = \frac{d_j^-}{d_j^- + d_j^+}$	CC_j^*: the relative closeness to the ideal solution	
Step 6	Ranking the result values	Ranking CC_j^* values		The highest CC_j^* value is the best choice

Table 4 The combined AHP-MCDM and mathematical programming approaches

Approaches	Authors	Applications	Specific areas
AHP	İrfan et al. (2022)	Energy	Prioritizing and overcoming biomass energy barriers
	Zhou and Yang (2020)	Energy	Risk management
TOPSIS	Kannan and Navneethakrishnan, (2020)	Industry	Parameter optimization
GP	Hocaoğlu (2019)	Defence	Target assignment opt
	Kaçmaz et al.(2019)	Industry	Shift Scheduling
AHP-TOPSIS	Hamurcu and Eren (2020a, b, c)	Transportation	Electric bus selection
	Kamalakannan et al., (2020)	Production	Supplier selection
	Hamurcu and Eren (2020a, b, c)	Transportation	Strategic planning
	Hamurcu and Eren (2020a, b, c)	Defence	Selection of unmanned aerial vehicles
	Yazıcı et al. (2022)	Healthcare	Evaluation of supply sustainability of vaccine alternatives
AHP-GP	Gür et al. (2017)	Transportation	Project selection
	Sharma et al. (2021)	Healthcare	Optimization of message communication during COVID-19 epidemic
	Cyril et al. (2019)	Transportation	Performance Optimization
	Hamurcu and Eren (2018)	Transportation	Project selection
AHP-MCDM-MP	Özcan et al., (2019)	Energy	Maintenance strategies opt
	Karaman and Çerçioğlu (2015)	Servis systems	Project Selection
	Özcan et al. (2017)	Energy	Maintenance strategy select

are conflicting objectives (Yang et al., 2016).The combined AHP-MCDM and mathematical programming approaches are shown in Table 4.

The mathematical formulation of the standard GP is as follows (Ignizio, 1976):

Considering the m objectives, we have,

$$Min\,Z = \sum_{i=1}^{m} \left(d_i^+ + d_i^- \right) \tag{1}$$

$$\sum_{j=1}^{n} a_{ij}x_j - d_i^+ + d_i^- = b_{i,\, i=1,\ldots\ldots,m, j=1,\ldots\ldots,n} \tag{2}$$

$$d_i^+, d_i^-\, and\, x_j \geq 0$$

The variables d_i^+ and d_i^- are positive and negative deviations from the target value of the $i$tch goal (bi); a_{ij} : *parameter*.

4 Electric vehicles in Turkey

Turkey is made up of a European and Anatolia part, has land part of 783562 km^2. Turkey has total 82 cities, 18 metropolitan municipality in these cities. Its total population that is 84 million, and ratio of 45% of these population lives in metropolitan municipalities. Strong population growth of 1.45% per annum and rapid urbanization has played an important role for development of Turkey. Turkey is one of the developing economies with achieving an average annual growth rate of 5.6% over the past 25 years and a GDP/capita of 9980 Euro.

Turkey is a country that dependent on outside some energy resources. Fossil-fuels are used many area and insdustry. Especially petrol needs place a big burden on the economy in many areas. Besides, the fossil-fuels based-air pollution problems is becoming a great environmental as in many countries.The number of motor vehicles and traffic load also are important cause of these problems. Thus, clear energy with their various resources appear to be one of the most efficient and effective roads for clean and sustainable development and environment in solution of these problems.

The reduction of oil dependency with use of alternative clean technology, especially in the transportation sector, are significantly important issues for Turkey. Moreover, Turkey has set some future targets to about use of clean technology due to international accords. Usage of clean technologies such as EVs are key factor to decrease and control the emissions and to develop a sustainable city life in especially metropolitan municipalities. It is predicted could be potential reduction in energy use and carbon emission with the use of EVs, and Turkey have been produces new policies in this direction.

Today, there are over 3 million EVs worldwide, and the number of EVs is increasing every day. But, the number of EVs in developing countries, such as Turkey is quite low. However, the state of Turkey aims to increase these statistics by investing in renewable energy types, lowering tax rates, and improving the existing infrastructure status. Turkey can quickly transition to EVs with ensure a strong design of infrastructure and some legal regulations for supporting the use of environmentally friendly systems in transportation in the near future. A total of 45000 EVs are planned to be on roads of Turkey in today (Kaya et al., 2020). One of the most important activity in this direction, vehicles that are main element of transportation, is production of domestic electric automobile. The Republic of Turkey started to design a 100% Electric automobile in 2017. The Turkish state promoted electric automobile that domestic production in the last of 2019 and explained that the domestic electrical automobile will be available for market in 2023. Besides, non-domestic electric vehicle industry is highly likely to have positive a growth rate during the next years in Turkey.

Turkey has targets on alternative energy vehicles as stated in the 2053 transport and logistics master plan. Projects and studies are carried out in order to achieve these goals. Some of them(UAB, 2022a, b):

- o The use of electric and alternative energy will be increased instead of fossil fuels on highways.
- o Increasing the number of electric and hybrid vehicles and establishing financing incentive models for this.

Table 5 Automobile sales by engine type: first three months of 2021–22

Engine type	January 2021		January 2022		Rate of change
	Number	Share(%)	Number	Share(%)	
Petrol	20.235	57,20	21.565	74,30	6,60%
Diesel	9.724	25,50	5.357	18,50	− 44,90%
Autogas	1.849	5,20	308	1,10	− 83,30%
Hybrid	3.467	9,80	1.656	5,70	− 52,20%
Electric	83	0,20	134	0,50	61,40%
Total	35.358	100	29.020	100	− 17,90%
Engine type	February 2021		February 2022		Rate of change
	Number	Share(%)	Number	Share(%)	
Petrol	26.829	60,00	27.210	72,30	1,40%
Diesel	12.222	27,30	5.576	14,80	− 54,40%
Autogas	1.809	4,00	1.007	2,70	− 44,30%
Hybrid	3.834	8,60	3.547	9,40	− 7,50%
Electric	55	0,10	301	0,80	447,30%
Total	44.749	100	37.641	100	− 15,90%
Engine type	March 2021		March 2022		Rate of change
	Number	Share(%)	Number	Share(%)	
Petrol	51.036	66,80	35.001	69,80	− 31,40%
Diesel	15.780	20,70	7.023	14,00	− 55,50%
Autogas	3.131	4,10	1.487	3,00	− 52,50%
Hybrid	6.236	8,20	6.024	12,00	− 3,40%
Electric	174	0,20	638	1,30	266,70%
Total	76.357	100	50.173	100	− 34,30%

Table 6 Automobile sales by engine type: last 3 years

Engine type	2019		2020		2021		Rate of change	
	Number	Share(%)	Number	Share(%)	Number	Share	2019–20 (%)	2020–21 (%)
Petrol	154.784	40,00	317.630	52,10	373,600	66,50%	106,40	17,60
Diesel	201.713	52,10	240.819	39,50	110,523	19,70%	19,40	− 54,10
Autogas	18.531	4,80	26.685	4,40	25,391	4,50%	44,00	− 4,80
Hybrid	12.006	3,10	24.131	4,00	49,493	8,80%	85,50	105,10
Electric	222	0,10	844	0,10	2846	0,50%	280,20	237,20
Total	387.256	100	610.109	100	561,853	100%	57,50	− 7,90

- o Promoting sustainable, environmentally friendly, efficient, low-emission and emission-free transportation systems at national, regional and local level.
- o Making infrastructure investments that will expand the use of electric and autonomous vehicles in all modes of transportation

Automobile sales by engine type in Turkey are shown in Tables 5 and 6. As can be seen from the tables, the sales of electric vehicles are increasing day by day in Turkey (Report, ODD,2022). Thus, determination of preference of electric vehicle purchase is more important decision problem for Turkey and developing countries.

5 Case study

In this section, the proposed analysis model, AHP-TOPSIS and GP, is applied with the aim of selecting a set of electric automobiles. The decision process is conducted according to a multi-criteria and multi-objective in compliance with the characteristics, requirements and constraints of problem. This problem is important subject for Turkey as in almost every country in the world. Developing country Turkey give an important to sustainable development. So the urban transportation, environmental sustainability and urban life are some of the most important component to sustainable development. It is aimed to minimize CO2 emission from transportation with this study in basic.

5.1 Research methodology

This research proposes a decision making model for the selection of electric automobile. Figure 1 outlines the methodological approach. Preliminary level in research methodology are formed determination of problem, identification of alternatives, collection of automobile information and determination of evaluation criteria. In the decision process, the AHP method, TOPSIS method, AHP-TOPSIS hybrid model and optimization with GP under the scenarios are formed. And finally comparison of results and analysis are made Table 7.

5.2 Problem setup and data

To provide expert judgment and consultations in decision making process, the authors formed a team, which consisted of twelve members (Table 8) to work side by side with the research team. The twelve members consisted of the industrial engineer, electric electronic engineer, and mechanical

Fig. 1 Research methodology

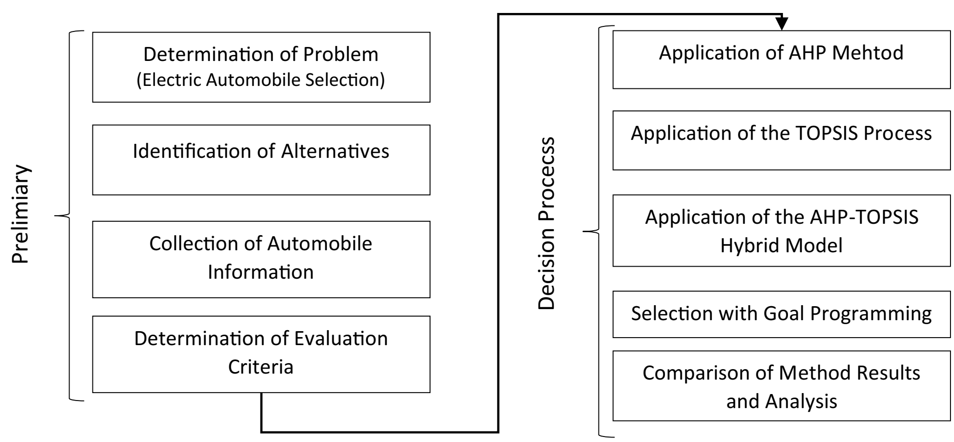

Table 7 Expert team

Professional	Level of education	Number of person	Statü
Industrial engineer	Phd	3	Academics
	Master	3	Transport planning department
Electric-electronik Engineer	Phd	2	Academics
	Master	2	Academics
Mechanical engineer	Phd	2	Academics
Total		12	

Table 8 Alternative electric automobiles and their specifications

Criteria	Unit	Alternative Automobiles									
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Maximum power	*kW*	240	554	340	135	210	100	150	160	385	503
Top speed	*Hp*	200	225	190	160	180	155	167	185	210	260
Acceleration (0–100 km/sa)	*sn*	6,1	3,9	5,7	6,9	6,8	9,9	7,9	5,2	4,3	2,4
Fuel economy	*kWsa/ 100 km*	19,4–22,5	22,5–18	19,1–16,1	14,0–14,6	18,9—18.5	14,3	14,7	16,8	19,6—17,6	18,6
Battery capacity	*kWh*	76,6/71	83,9/80,7	83,9/80,7	42,2	80/73.83	39,2	64	72,6	107,8	70
Range	*km*	372–425	521	590	345–330	460	305	484	481	649	539
Quick charge time	*min*	31	8	10	45	34	47	54	18	31	40
Full charge time	*sa*	8	8,5	8,5	15	7,5	6	9,4	6,1	10	7
Purchasing price	*$*	182.987	164.613	126.193	73.467	136.300	48.433	70.333	29.667	148.259	94.490

Mercedes (2022), Hyundai (2022), Tesla (2022), BWM (2022)

engineer. Three industrial engineer in these team work to transportation department at the municipality. A mini survey of expert team was carried out to identify the relative importance of each criterion and to derive the AHP weights. The results obtained were used to later structure and to ensure input the TOPSIS and GP model. Table 7 provides a summary of information of ten alternative electric automobiles.

Determinate evaluation criteria according to expert opinion and their explanation are follow(evaluation criteria and references in Table 9):

Maximum power (C1): Maximum power provides the motive force required for the EVs to accelerate.

Top speed (C2): Top speed (km/h): higher the speed or in nominal range, the better as convenience is increased. (Das et al., 2019).

Acceleration (C3): Consumers prefer lower acceleration time for NEVs (Paul Helveston et al., 2015).

Fuel economy (C4): Low-energy-consumption is one of the most importan factor for the use of vehicles for transportation purposes.

Battery capacity (C5): the battery capacity represents the maximum amount of energy that can be extracted from the battery under certain specified conditions (Das et al., 2019). EVs operate in a limited distance and time due to the battery limitation. Battery capacity and charging technology of EVs have been improving day by day, which emerge to be an important factor in affecting the decision-making of designing EVs.

Range (C6): Driving mileage is a point that consumers pay special attention to NEVs (Paul Helveston et al., 2015; Huang and Qian, 2018).

Quick charge time (C7): Lower- quick charge time is among the critical factor for consumers preference.

Full charge time (C8): Charging time is an important factor affecting consumers' use of NEVs.

Purchasing price (C9): The Price is a key factor affecting consumers' purchase of new energy vehicles (Ma et al., 2019b; Chen et al., 2019a, b; Huang and Qian, 2018; Lin and Wu, 2018).

5.3 Criteria weights via AHP

In study, the AHP provides the importance levels of the electrical vehicles evaluation criteria. AHP, a MCDM methodology, has been widely used a method by both practitioners and researchers in addressing complex decisions. The AHP helps decision makers in terms of factors like to shows the relationship between the evaluation criteria, to integrate expert's information and experience, and to calculate relative magnitudes in this study.The comparison matrix and evaluation of criteria according to expert

Table 9 Evaluation crteria

References	C1	C2	C3	C4	C5	C6	C7	C8	C9
Neves et al. (2019)					√				√
Egner and Trosvik (2018)						√			√
Chen et al. (2020)				√	√				
Jena (2020)									√
Egbue and Long (2012)	√	√	√			√			√
Weldon et al. (2018)				√	√	√			√
Kang and Ceder (2009)							√		
Zhang et al. (2018a, b)						√	√	√	√
Sovacool et al. (2018)		√		√		√	√	√	√
Azadfar et al. (2015)							√	√	
Yang et al. (2013)						√	√	√	√
Habib et al. (2015)					√		√	√	
Coffman et al. (2015)						√	√	√	√
Ma et al. (2019)	√				√		√	√	
Skippon and Garwood (2011)			√			√			
Xu et al. (2017)						√			√
Axen et al.(2009)	√			√	√				√
Faria et al. (2012)				√	√	√			√
Bolduc et al. (2008)	√			√					√
Franke and Krems (2013)									
Jensen et al. (2013)		√				√			
Mukherjee and Ryan (2020)									√
Ecer (2021)	√	√	√	√	√	√	√	√	√

Table 10 The comparison matrix for criteria

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	Eigeven
C1	1000	3000	3000	1000	1000	0333	1000	1000	1000	0,10877
C2	–	1000	3000	1000	0333	0333	1000	3000	0333	0,07374
C3	–	–	1000	0200	0200	0143	0,333	0333	0143	0,02543
C4	–	–	–	1000	0333	0333	0333	1000	0200	0,06653
C5	–	–	–	–	1000	1000	3000	3000	3000	0,20310
C6	–	–	–	–	–	1000	1000	3000	1000	0,18163
C7	–	–	–	–	–	–	1000	3000	0333	0,10714
C8	–	–	–	–	–	–	–	1000	0333	0,05782
C9	–	–	–	–	–	–	–	–	1000	0,17583

CI = 0,099,562, CR = 0,06866, RI = 1,45

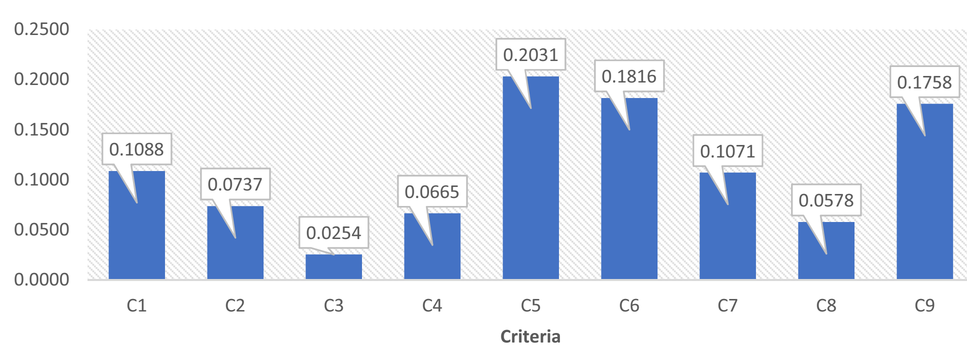

Fig. 2 The important levels of criteria

opinion is shown in Table 10. Values of criteria are shown in Fig. 2 in result of evaluation.

In terms of the weights of criteria, the following analyses can be made:

- The most important criteria are C5, C6, C9, C1, and C7.
- These five criteria involve customers the most important five preferences in many researches.
- Besides, it is study on C5, C6, C9, C1, and C7 to improve and dissemination of EVs in todays.
- These five criteria involve 80% of all evaluation criteria. So, these are factors that should be overemphasized in the selection process.

Table 12 Final ranking of the solutions with TOPSIS

Alternatifler	A+	A −	CCi	Rank
A_1	0,0946	0,0435	0,3150	10
A_2	0,0702	0,0824	0,5397	5
A_3	0,0580	0,0769	0,5702	4
A_4	0,0949	0,0534	0,3598	9
A_5	0,0781	0,0504	0,3919	8
A_6	0,0975	0,0668	0,4064	7
A_7	0,0798	0,0630	0,4410	6
A_8	0,0582	0,0904	0,6082	1
A_9	0,0639	0,0852	0,5714	3
A_10	0,0569	0,0766	0,5739	2

5.4 Hybrid AHP-TOPSIS model

Present paper uses the hybrid of AHP and TOPSIS. An integrated AHP- TOPSIS methodology is utilized to structure and prioritize the factors. Table 11 shows the weighted normalized decision matrix for solutions.

Table 12 shows the evaluation results and ranking by using TOPSIS. The proposed model results show that A_8 automobile is the best alternative with CCi value of 0,6082. Then, A sensitivity analysis is performed to analyse the two phases AHP and TOPSIS methodology proposed in decision process. For this reason, unweighted TOPSIS method were applied.

5.5 Goal Programming model based on AHP

Earlier, Gür et al. (2017), Hamurcu and Eren (2018), Cyril et al. (2019) used in combination AHP-GP model in their studies. In the AHP-GP model, the objective function includes deviation variables associated with the four criteria goals. It will seek to minimize such deviations from desired levels. The revised objective function is given in Eq. (1). Moreover, a set of constraints, as shown in Eq. (2), will be added to reflect the constraints target of B (Battery capacity), R (Range), P (Purchasing price), Pw (Maximum power), Q (Quick charge time) in each of the "goal constraints". An equation associated for selection of only one vehicle will be added. The goal programming model is given in Table 13. The most important five criteria are determinate by pareto analysis (Fig. 3.) and these criteria used as constraint for GP model. We used four criteria by the reason of we can express it as a constraint. The range constraint is used instead of battery capacity in model.

Table 11 Weighted normalized decision matrix for solutions

Alternatives	Criteria								
	C1	C2	C3	C4	C5	C6	C7	C8	C9
Weights	0109	0074	0025	0067	0203	0182	0107	0058	0176
A_1	0026	0024	0008	0025	0063	0047	0030	0016	0086
A_2	0060	0027	0005	0024	0071	0061	0008	0017	0077
A_3	0037	0023	0007	0021	0071	0070	0010	0017	0059
A_4	0015	0019	0009	017	0037	0040	0043	0031	0035
A_5	0023	021	0009	0022	0065	0054	0033	0015	0064
A_6	0011	0018	0013	0017	0035	0036	0045	0012	0023
A_7	0016	0020	0010	0018	0057	0057	0052	0019	0033
A_8	0017	0022	0007	0020	0064	0057	0017	0012	0014
A_9	0042	0025	0006	0022	0095	0077	0030	0020	0070
A_10	0055	0031	0003	0022	0062	0064	0039	0014	0044
	max	*max*	*min*	*min*	*max*	*max*	*min*	*min*	*min*
A+	0060	0031	0003	0017	0095	0077	0008	0012	0014
A −	0011	0018	0013	0025	0035	0036	0052	0031	0086

Table 13 The goal programming model

The objective function		
Min Z $= 0,2031*(d_1^- + d_1^-) + 0,1816*(d_2^- + d_2^-) + 0,1758*(d_3^+) + 0,1088*(d_4^- + d_4^+) + 0,1071*(d_5^- + d_5^+)$		(1)
Subject to;		
Constraint of "battery capacity"	$\sum_{i=1}^{10} b_i x_i + (d_1^- - d_1^+) = B$	(2)
Constraint of "Range"	$\sum_{i=1}^{10} m_i x_i + (d_2^- - d_2^+) = R$	(3)
Constraint of "Price"	$\sum_{i=1}^{10} s_i x_i + (d_3^- - d_3^+) = P$	(4)
Constraint of "Power"	$\sum_{i=1}^{10} h_i x_i + (d_4^- - d_4^+) = Pw$	(5)
Constraint of "Quick charge time"	$\sum_{i=1}^{10} q_i x_i + (d_5^- - d_5^+) = Q$	(6)
The model also includes the following hard constraint	$\sum_{i=1}^{10} x_i = 1$	(7)

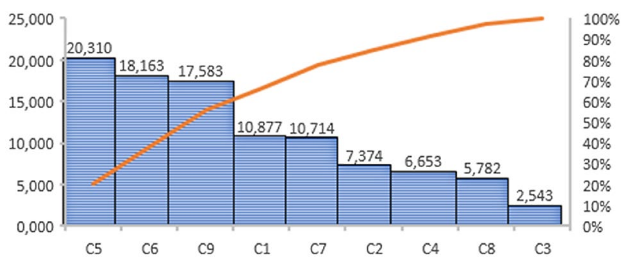

Fig. 3 The most important five criteria-Pareto analysis

Table 14 Scenarios

Scenarios	Range(km)	purchasing price($)
S1	200	50.000
S2	400	50.000
S3	200	100.000
S4	400	100.000
S5	200	150.000
S6	400	150.000

Decision variable:

$$x_i = \left\{ \begin{array}{c} 1 \textit{ if the ith alternative is selected}, \\ 0 \textit{ otherwise}; i = 1, 2, \ldots, 11 \end{array} \right\}$$

Parameters:

The objective function is to minimize the total weighted deviations from the goals that satisfy the above constraints. It can be expressed as follows:

Different scenarios are applied such as budget and range in the GP model. This values of constraints and six scenarios are shown in Table 14.

6 Results

Results of the MCDM analyse and the optimum results with GP under the scenarios are given in Table 15. The TOPSIS method and weighted TOPSIS method's results are not same. So weights of criteria effect selection results. The important levels of criteria are not the same. So, to use AHP-TOPSIS hybrid model is more suitable than to use only TOPSIS model. The GP model helps to decision makers for their evaluation of different scenarios. According to AHP -TOPSIS method, the best selection is A_8 alternative. We have shown in bold the best selection alterntive found in the TOPSIS/AHP-TOSIS and using symbol "✓" the optimum select results found by AHP-GP/GP in Tables 15 and 16. Other selection results are shown in Table 15.

Sensitivity analysis with equal number of constraints and same constraints, same evaluation factors and same criterion weights is shown in Table 16. When the results are examined, it is seen that the selection and ordering made are independent of each other. We can say that only the criterion weights affect the TOPSIS ranking method results. However, AHP weights do not affect the GP model in this problem. AHP-TOPSIS and TOPSIS method results and GP model selection results do not support each other.

The criterion weights do not affect the GP model. However, the selected criteria and the number of criteria

Table 15 Results and analysis

Alternatives	TOPSIS		AHP-TOPSIS		AHP-GP/GP					
	CCi	*Rank*	*CCi*	*Rank*	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*
A_1	0,3998	7	0,3150	10		–	–	–	✓	✓
A_2	0,6446	2	0,5397	5	–	–	–	–	–	–
A_3	0,6012	3	0,5702	4	–	–	–	–	–	–
A_4	0,3187	10	0,3599	9	–	–	–	–	–	–
A_5	0,4193	6	0,3920	8	–	–	–	–	–	–
A_6	0,3835	8	0,4064	7	–	–	–	–	–	–
A_7	0,3735	9	0,4410	6	✓	✓	–	–	–	–
A_8	0,5869	4	**0,6082**	**1**	–	–	–	–	–	–
A_9	0,5754	5	0,5714	3	–	–	–	–	–	–
A_10	**0,6488**	**1**	0,5739	2	–	–	✓	✓	–	–

Table 16 Sensitivity analysis

Methods	Criteria/Constraints									Selected automobile/ranking									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
TOPSIS	✓				✓	✓	✓		✓	9	**1***	2	10	6	8	7	5	4	3
AHP-TOPSIS	✓				✓	✓	✓		✓	10	5	3	9	8	7	6	**1***	2	4
GP	✓				✓	✓	✓		✓							✓			
AHP-GP	✓				✓	✓	✓		✓							✓			
TOPSIS	✓	✓				✓	✓		✓	10	**1***	3	8	9	6	7	4	5	2
AHP-TOPSIS	✓	✓				✓	✓		✓	10	4	3	8	9	6	7	**1***	5	2
GP	✓	✓				✓	✓		✓								✓		
AHP-GP	✓	✓				✓	✓		✓								✓		
TOPSIS	✓	✓			✓	✓		✓		7	**1***	4	10	6	9	8	**5**	3	2
AHP-TOPSIS	✓	✓			✓	✓		✓		7	2	4	10	5	9	8	**6**	**1***	3
GP	✓	✓			✓	✓		✓											✓
AHP-GP	✓	✓			✓	✓		✓											✓
TOPSIS	✓	✓				✓			✓	10	2	5	8	9	7	6	4	3	**1***
AHP-TOPSIS	✓	✓				✓			✓	10	7	4	8	9	5	3	2	6	**1***
GP	✓	✓				✓			✓								✓		
AHP-GP	✓	✓				✓			✓								✓		
TOPSIS						✓		✓	✓	10	9	5	8	6	2	4	**1***	7	3
AHP-TOPSIS						✓		✓	✓	70	9	6	5	8	3	2	**1***	7	4
GP						✓		✓	✓						✓				
AHP-GP						✓		✓	✓						✓				

change the results both in the ranking method and in the GP model. This shows that the number of criteria or the number of constraints in the mathematical model should be well defined in decision making processes. The most appropriate criteria should be chosen for the decision processes, and the most suitable number and quality of constraints should be used in the mathematical model to best reflect the problem. Finaly, the AHP method, together with the Pareto analysis, played an important role in determining the constraints for GP.

The current work implements the GP approach as it has many advantages over other decision making tools:

- GP model provides flexibility and convenience for decision makers. It can add decision makers' constraints to the model effectively. It can collect conflicting and mutiple objectives in the same model.
- GP is a very systematic and less complex approach which seems good enough to represent the key principles of real-life MCDM problems.

7 Conclusion

EVs become more popular day by day under the environmental sensitivity. It is seeming that, although EV have many technical challenges, such as battery technology, charging technology, electric motor technology, it will replace completely existing fuel-vehicles in the near future. Finally, deployment of zero-emission EVs in urban areas will be an important tool for reducing air pollution in cities. This situation (zero-emission vehicle) will ensure to improve urban transportation and will be as one of the factors of sustainability based urban transport development.

This study presents multi criteria decision making model to help consumers in their preference in proliferation process of EVs. Besides, optimization process helps to determine the most suitable vehicle with established GP model under the different scenarios. These selection processes are valuable for government agencies and EV manufacturers looking to promote EVs and overcome environmental pollution.

The limitations with the used approaches for analysis of decision process; Independence between criteria in AHP method can lead an inaccurate result. TOPSIS method works on the Euclidean distance. So, a strong deviation of one indicator from theideal solution strongly influences the results. GP model provides flexibility in this point. The limitations with the study: It used 10 electric vehicle alternatives in study that are sold and have a market in Turkey. In the study, the five most important evaluation constraints are determined to be used in the GP model.

In future studies, it can be evaluated new policies and public supports using MCDM, financial incentives such as tax reductions and purchase subsidies to improve and to generalize EVs. It can be made studies such as evaluation and prioritisation of policies to accelerate electric vehicle adoption, beyond the purely technical and economic dimensions of EVs. Besides, despite the main focus of the paper being on vehicle selection, recharging infrastructure of cities consider an important factor shaping the EVs market. Many study are in the literature (Wang, et al., 2019). Thus, in future studies, recharging infrastructure should structure and generalize to considered the specifications of EVs. In addition to this, This paper use AHP-TOPSIS and GP model are applied separately. In future work, a integrated approach can be presented for this problem by using AHP-TOPSIS-GP.

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Declarations

Conflict of interest The authors declare they have no competing interests.

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