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Evaluation of the alternatives of introducing electric vehicles in developing countries using Type-2 neutrosophic numbers based RAFSI model

Ilgin Gokasar [a], Muhammet Deveci [b,c,*], Mehtap Isik [d], Tugrul Daim [e,h,**], Aws A. Zaidan [f], Florentin Smarandache [g]

[a] Department of Civil Engineering, Bogazici University, 34342 Bebek, Istanbul, Turkey
[b] Department of Industrial Engineering, Turkish Naval Academy, National Defence University, 34940 Tuzla, Istanbul, Turkey
[c] Royal School of Mines, Imperial College London, London SW7 2AZ, UK
[d] Department of International Trade, Bogazici University, 34342 Bebek, Istanbul, Turkey
[e] Portland State University, Portland, OR, USA
[f] SP Jain School of Global Management, Lidcombe, Sydney, NSW 2141, Australia
[g] Mathematics and Science Division, University of New Mexico, 705 Gurley Ave., Gallup, NM 87301, United States
[h] Chaoyang University of Technology, Taichung City, Taiwan

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ABSTRACT

This study focuses on implementing electric vehicles (EVs) in developing countries where energy production is mainly based on fossil fuels. Although for these countries the environmental short-run benefits of the EVs cannot offset the short-run costs, it may still be the best option to implement the EVs as soon as possible. Hence, it is necessary to evaluate the alternatives to introducing EVs to the market due to the environmental concerns that created an opportunity for some developing countries to catch up with the international competition. Therefore, we develop a case scenario to explore the decision-making process in implementing the EVs with three alternatives and twelve criteria. We solve the decision-making problem by using Type-2 neutrosophic numbers (T2NNs) based on the RAFSI (Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval) method. The proposed model combines the advantages of the RAFSI technique, and it applies T2NNs to address the uncertainties. The results show that the alternatives that may suspend the implementation of the EVs are inferior. Direct implementation of EVs is prioritized. The policy implications of the results are discussed in the study.

1. Introduction

The environmental benefits of EVs are obvious in various aspects. Different types of EVs are proposed to be implemented for the sake of environmental protection (Yuan and Cai, 2021). The EVs market is getting bigger and expanding to supply different tastes (Tchetchik et al., 2020; Benzidia et al., 2021) The increasing number of patents show that EVs are the future of the automotive industry (Yuan and Li, 2020; Hain et al., 2022; de Paulo et al., 2020). However, the extra demand for electricity created by the increased use of EVs should be a concern for decision-makers. Unsurprisingly, under some circumstances, the cost of using EVs can exceed its benefits in the short run time.

A recent study (Sahin, 2022) put forward an interesting case analysis in a developing country, Turkey. The results show that in the total traffic demand, there is optimal use rate of electrical Autonomous Vehicles (AVs) which is between 30 % and 50 %. Also, the increase in the number of these electrical AVs can affect the occurrence of traffic accidents. The major reason behind this appears to be the resource of electricity supply in the country, in addition to the infrastructural challenges. As electricity is primarily produced from fossil fuels in Turkey, the environmental costs of using electrical AVs exceed its benefits.

The emergence of specific technologies may differ across countries (Li et al., 2021). Moreover, the transformation of the existing system is a challenging issue and may fail because of various reasons, from

* Correspondence to: M. Deveci, Royal School of Mines, Imperial College London, London SW7 2AZ, UK.
** Corresponding author.
E-mail addresses: ilgin.gokasar@boun.edu.tr (I. Gokasar), muhammetdeveci@gmail.com (M. Deveci), ozcanli@boun.edu.tr (M. Isik), ji2td@pdx.edu, tugrul.u.daim@pdx.edu (T. Daim), smarand@unm.edu (F. Smarandache).

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macroeconomic conditions to the national industry's international position. Technological strategies must be determined over micro and macro economies as well as the stakeholders' needs (Mohamad and Songthaveephol, 2020; Wu et al., 2021; Ball et al., 2021; Ye et al., 2021). Although the economic and technical conditions are appropriate, society's acceptance of the new technology may also be an obstacle (Adu-Gyamfi et al., 2022; Featherman et al., 2021). Some policy mixes in both macro and micro levels that can cure at least some of the problems and prepare the existing system for the transformation period (Raven and Walrave, 2020; Deuten et al., 2020). Even some major changes in culture and consumer behavior that are required can be promoted by the policy makers (Köhler et al., 2020; Jiang et al., 2022; Moon et al., 2021; Jaiswal et al., 2021; Huang et al., 2021a). The company-wide and system-level changes must be planned by respecting the existing traditions (Wesseling et al., 2020; Singh et al., 2021; Llopis-Albert et al., 2021b; Babar and Ali, 2021). All the evidence from the literature clue in the difficulties of policymaking in implementing EVs regarding its economy-wide impacts as well as the technology diffusion in society. In this study, we aim to explore the decision-making process, and to reach some policy implications in implementing EVs when environment-friendly energy production is an additional concern in a country. Different scenarios that simulate real-life conditions and reveal the bottlenecks of the transition problems are possible to consider analyzing this strategic decision-making process (Kishita et al., 2020; Krawinkler et al., 2022). The major concern that we focus on is the structure of the energy market, and the rate of change in fossil fuel consumption as the use of EVs increases in traffic.

The infrastructural investments are expensive and constitute a significant financial constraint in both the transportation sector and energy sector. The impact of transformation on the automotive industry is more obvious, and it may be required to support the stakeholders financially (Llopis-Albert et al., 2021a; Gao and Zhang, 2022). While implementing EV technology requires a lot of investment, it has a strong impact on the whole economy (Tamba et al., 2022). This is especially true in terms of how the transformation process affects the energy market most directly where as the demand for fossil fuels for vehicles decreases, the demand for electricity and hydrogen increases. Fossil fuel consumption is expected to be reduced with the implementation of EVs in transportation. It is more likely that the implementation of EVs achieves successful climate actions in a shorter time if electricity production does not require fossil fuels. Investments in renewable energy resources in developed countries have long since started this process (Pereira et al., 2022). However, fossil fuels are still the major sources to produce electricity in most of the developing world. For example, hydrogen demand is expected to be doubled by 2040 (Park et al., 2022), yet the paradigm shift that comes along with the new EV technologies can be an opportunity for those developing countries who are trying to catch up with the global competition in the automotive industry (Altenburg et al., 2022). In that respect, it is not about whether to implement EVs or not, but it is about how to implement the EVs so that the utilization can be optimized. Therefore, it is vital to offer decision-makers in developing nations an understanding of alternate methods for the utilization of electric vehicles (EVs). Fuzzy based decision making models have been successfully integrated into various problems (Zhou et al., 2022; Gopal and Panchal, 2021).

In this study, a Type-2 neutrosophic numbers (T2NNs) based methods RAFSI method is applied to choose the best alternative among the three alternatives. The T2NNs are used to address incomplete, indeterminate, and inconsistent information, which is why T2NNs are effective at handling uncertain information. RAFSI provides flexible decision-making and simulation of different risk levels to effectively control the robustness of the results. The analysis results indicate that the improved model based on T2NNs is a powerful, robust, and applicable tool that can be applied to solve decision-making problems.

The rest of this study is structured as follows. Section 2 provides a literature review. Section 3 defines the problem, alternatives, and criteria. The methodology is explained in Section 4. The case study, results, discussion, and policy implications are provided in Sections 5, 6, and 7, respectively. Finally, the conclusion of the study is explained in Section 8.

2. Literature review

According to a study regarding driven factors of renewable energy development, the best way to promote renewable energy is through high feed-in-tariff (FIT) pricing, simple transmission access, and minimal transmission adjustments (Alagappan et al., 2011). From a different perspective, energy itself is known as a "strategic commodity". Therefore, especially in developing countries, sustainable energy is a trend-topic, and renewable energy transition from fossil fuel combustion as a primary energy supply is a long-term must (Sen and Ganguly, 2017). Moreover, incrementation in investment in the region's development of renewable energy will be boosted by economic growth (Xu et al., 2019). In addition, to advance the growth of renewable energy power generation, it will be beneficial to support the development of renewable energy technologies that will lower development, maintenance costs, and increase reliability, applicability, and energy conversion efficiency (Dinçer et al., 2022). Altogether, it can be concluded that encouraging renewable energy development could create a better future not only for the electric vehicle industry but also for a sustainable economy and environment.

Encouraging the use of electric vehicles could be done in various ways. Benefits gained from it could exceed its costs. Lifting barriers in front of EV adoption is the key to boosting the EV population. Local and national governments may take action to increase the rate of transition to EVs. Incentive policies such as operation subsidy, purchase subsidy, access to high occupancy vehicle lanes, and free parking could be the points in a written list (Kwon et al., 2018). Other than the governmental assistance, the flexibility provided by regulations could result in good feedback. Madina et al. (2016) state that accesses to private home charging, in particular, is anticipated to be a significant factor in the adoption of electric vehicles as long as owners can cover high yearly mileage, charge their EVs more cheaply at night, and receive incentives for EV purchases. To sum up, accomplishing proper ways to encourage the use of electric vehicles could increase the civilization of the country in many parts.

However, creating financial support results in different consequences. First of all, fuel tax directly affects usage and its capital could become a possible source for subsidies. The average gallon of gasoline in the United States costs forty cents more in state and federal taxes than it would without those taxes. This amounts to $8 billion in annual tax receipts (EIA, 2008). Fuel taxes may not originally have been developed for environmental purposes, but their impact is certainly ecological (Parry and Small, 2005). Another outcome is that implementing a carbon tax plays a significant role in climate change actions. If fiscal revenues aren't redistributed, carbon taxes will impose a higher cost on polluters than either command-and-control policies or emissions trading systems with an initial free allocation of permits (Keohane et al., 2017). Carbon taxes have been a popular idea among economists and international organizations (EEA, 1996; OECD, 1996). In the future, vehicle tax reform for internal combustion engines could be a new course of action. Although there may be some discomfort for consumers, the transition could be more sustainable financially. For example, Norway started this procedure years ago. In 2007, the travel part of the tax was replaced by the potential intensity of the vehicle's CO_2 emissions (Ciccone, 2018).

3. Problem definition

The latest climate events and their social and economic effects enforce an ultimate change in the traditional way of modern life. The transportation sector is carrying some burden of this transformation as well. From pollution control to energy efficiency, various concerns are being closely watched. Clean and efficient alternatives are expected to be developed. Using electrical vehicles (EVs) is highly encouraged especially because of their positive impacts on the environment. However, EVs require significant infrastructural investments. In this study, three alternatives to the EV adaptation process are analyzed using decision-making with 4 aspects and 12 criteria. The decision hierarchy of the decision-making problem is illustrated in Fig. 1.

3.1. Definition of alternatives

The definition of alternatives is explained in the following:

A_1: Encouraging renewable energy development: Energy is the world's most valuable asset. Today, most energy is provided by fossil fuels, yet the consequences of climate change cannot be disregarded (Stern and Stern, 2007). Economic damage caused by climate change could equal the whole cost of World Wars I and II. It also addresses environmental concerns. Renewable energy production could be the light that humanity is looking for to thrive on our only planet.

A_2: Encouraging the use of electric vehicles: The widespread availability of electric vehicles is a trend that can be seen in both developed and developing countries. The source of the electricity that will be utilized in EVs is the most contentious aspect of this discussion because it is the most important question. Aside from that, electric vehicles have significantly fewer greenhouse gas emissions than vehicles powered by internal combustion engines. The promotion of the use of electric vehicles will make a significant contribution to the accomplishment of the goals of sustainable development. The adoption of electric mobility across the globe is helping to lessen humankind's negative impact on the environment, lessen reliance on fossil fuels, and broaden the range of available energy sources for transportation (Onat and Kucukvar, 2022).

A_3: Regulation of the existing system through taxation and penalties: Because the primary goal of changing the existing system is to reduce GHG emissions and break free from the energy-dependent position caused by fossil fuel combustion, governments could enact new legislation to regulate the existing system through taxation and penalties. From the Kyoto Protocol in 1997 to the Paris Agreement in 2015, this approach has been legally popular and active. According to Goulder (2020), interactions between policy efforts and the financial system have a significant impact on policy reforms' political viability, distributional equality, and cost-effectiveness.

3.2. Definition of criteria

(1) Social and Political Aspect:

C_1: Social acceptance (benefit): The usefulness of any novelty intended for society is proportional to its acceptance by society. The impact of alternatives on society and people's reactions to them are critical variables in determining their efficacy. The user's comfort with the use of the technology also has a considerable impact on whether they intend to employ auto systems or renewable energy sources (Park et al.,2018).

C_2: Reduced political support (cost): Decision-makers must win public support, and the simplest way to do so is to increase their level of comfort. Aside from reducing GHG emissions, the EU's energy crisis caused by the Russia-Ukraine war needs alternate energy sources and new taxes. For example, the results of a survey done in Switzerland on changing support for renewable energy sources are particularly fascinating. It also revealed the biggest tendencies toward higher levels of support since the war, with slightly under a third of respondents increasing their support (Steffen and Patt, 2022).

C_3: Enhanced social inclusiveness (benefit): The social inclusivity of the alternatives is an essential problem because the usage areas of these alternatives may be limited. These advances necessitate conscious people to reach their full potential. The key concerns have been identified as familial factors that impact purchasing decisions, a lack of trust in EVs because they use a developing technology, and related societal difficulties because most consumers are not early adopters (Goel et al., 2021).

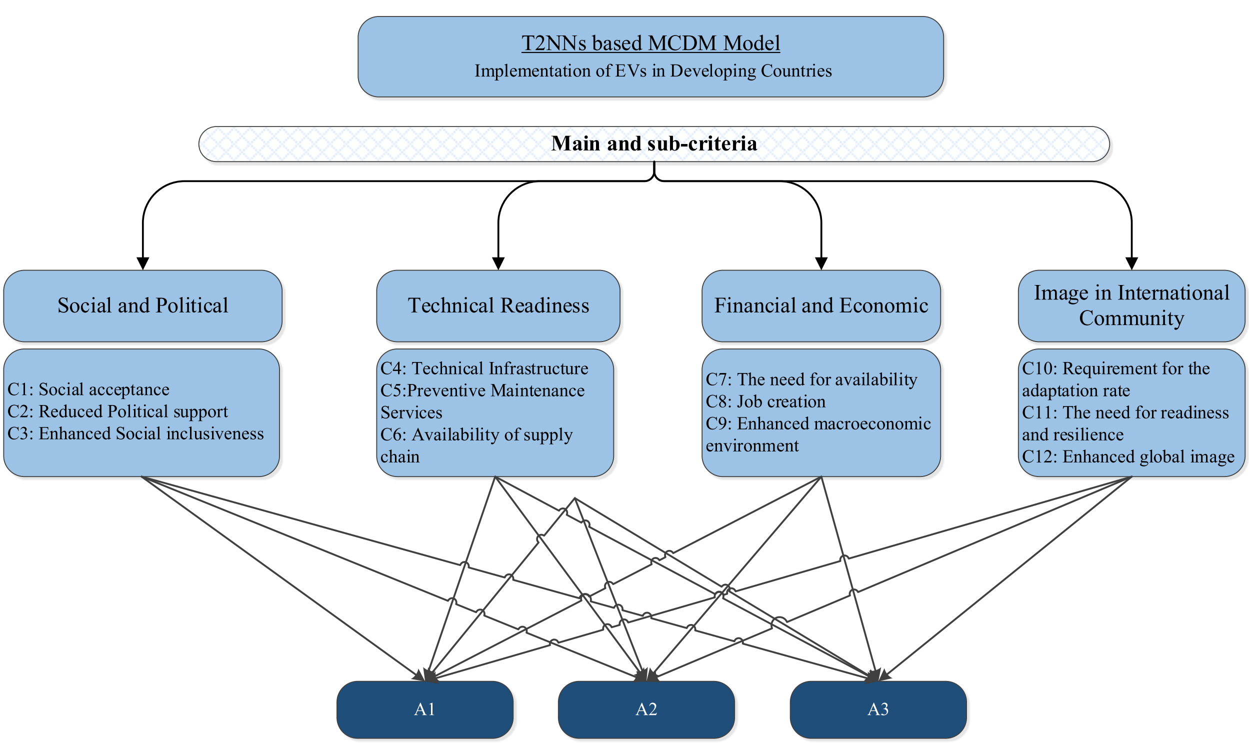

Fig. 1. The decision hierarchy of the decision-making problem.

(2) Technical Readiness Aspect:

C_4: Need for existence of technical infrastructure (cost): The use of electricity as a source of power is necessary for electric vehicles. They will require specialized infrastructure to function properly. Although there has been an increase in investment in infrastructure as a result of this market's expansion over time, there is still not enough public infrastructure to meet the demand. At this time, existing gas stations will house fast-charging infrastructure with high power of up to 350 kW. This will be the case for Ireland, the United Kingdom, the United States, and Germany, as well as the Tesla Supercharger network (Funke et al., 2019).

C_5: Need for existence of preventive maintenance services (cost): Because of the way they are built, renewable energy systems like solar panels and electric vehicles need to have regular maintenance performed for them to be used for extended periods. In contrast to the framework that has been established for electric vehicle services, renewable energy facilities already have a well-established service infrastructure in place. As was to be anticipated, maintaining the considered framework in a working state for a longer time, and consequently increasing the device's accessibility, results in a greater amount of energy given, and consequently, a higher income (Rinaldi et al., 2017).

C_6: Availability of supply chain of physical capital to implement the alternative (benefit): The growing demand for EVs and renewable energy necessitates the supply chain of items such as batteries, cells, technologies, and so on. The most common battery type is Lithium-Ion, and according to economic theories, if manufacturers are unable to make enough batteries to fulfill demand, the EV business will suffer. Because of major technological advancements, changes in battery structural design, changes in the supply chain and manufacturing process, as well as network relationships, the transition to electromobility creates uncertainty in the automotive supply chain (Marcos et al., 2021)

(3) Financial and Economic Aspect:

C_7: The need for availability of financial support (cost): When the project is completed, financial support is the most important factor. To make aspirations a reality, both renewable energy sources and electric vehicles must be economically sustainable. Penalties and taxation are two methods that governments could use to raise cash. Environmental taxes, for example, are used to alter the overall price of producing power from fossil or non-fossil sources (Abdmouleh et al., 2015).

C_8: Job creation (benefit): The range of the EV and renewable energy industries creates a huge number of job opportunities. For instance, the maintenance and repair of EVs differ from those of vehicles with internal combustion engines. Although additional jobs are projected to be produced in the household power industry, as stated in the preceding section, employment growth estimates are provided for both the battery manufacturing and charging network businesses (Becker et al., 2009).

C_9: Enhanced macroeconomic environment of the country (benefit): Every country has priorities that are directly tied to its geographical location and political status. Some EU members could redistribute resources to increase renewable energy sources, while other countries must prioritize public welfare. Furthermore, countries with economic insecurity face greater dangers than economically stable countries. Because of the two-way causal relationship between economic growth (GDP per capita) and renewable energy, per capita income influences the development and consumption of renewable energy, and encouraging economic development is beneficial to the growth of renewable energy (Shakouri and Khoshnevis Yazdi, 2017).

(4) Image in International Community Aspect

C_{10} Requirement for the adaptation rate of the industries to the regulations (cost): To mitigate the effects of climate change, industrialized and developing countries with the ability to change are compelled to act. The latter differs from the former in that emerging countries' growth may be hampered due to the limited use of ecologically unfriendly resources. However, the benefits of environmentally friendly technologies (EFT) may outweigh their costs. Annual forages planted during the fallow season produced more energy than they consumed, resulting in a lower energy ratio than in conventional cropping systems (Deng et al., 2021).

C_{11}: The need for readiness and resilience to climate change (cost): Governments are being forced to take climate action in transportation. Such agreements are mainly signed by developing countries. The extent to which current infrastructure is robust and prepared for disasters is critical in the decision-making process. Infrastructure could be harmed if enough precautions are not taken and no plans are made to prepare for future disasters. Infrastructure must be available if the new transportation system is to be integrated. The growing number of EVs may cause concerns in the future due to oversupply; however, countries may be able to tackle these issues by investing in the industry with less money than projected. Payback guarantee issues could be resolved by integrating renewable energy sources with EV charging stations (Alghoul et al., 2018).

C_{12}: Enhanced global image of the government (benefit): In today's global environment, a government is no longer the sole decision-maker for international community-related acts. Global images are increasingly crucial for governments as nations become more intertwined through trade and financial difficulties. Governments take steps to strengthen their international power, comfort, and reputation. Climate change measures have been one of the most important topics related to reputation in recent years. Furthermore, making a decision may affect other countries due to agreements. As a result, governments must use greater caution when executing movements. Despite officials at the Ministry of Environment seeing the national benefit of forest preservation and carbon trading mechanisms when compared to the Ministries of Foreign Relations (MRE) and Science and Technology (MS&T), this ministry's role in universal agreements is negligible (Lahsen, 2013).

4. Methodology

Zadeh (1965) introduced the fuzzy set theory to address the uncertainties in knowledge. Afterward, Atanassov (1986) generalized the fuzzy sets theory to the intuitionistic fuzzy sets that represent the membership and non-membership functions. Later, the neutrosophic sets were presented by Smarandache as an extension of fuzzy sets in (Smarandache, 1998). Neutrosophic sets have been successfully applied to decision problems (Abdel-Basset et al., 2022; Mishra et al., 2021; Donbosco and Ganesan, 2022; Broumi et al., 2023). The membership functions are illustrated in Fig. 2. In this section, some of the fundamental notations and operations are provided on Type-1 neutrosophic and Type-2 neutrosophic sets, and the steps of the proposed decision-making model are given as follows:

4.1. Type-1 neutrosophic set

Definition 1 (Smarandache, 1998). Let F be a universe of discourse. A neutrosophic set $\wp$ in F is represented by truth $\pi_{\wp}(f)$, indeterminacy $\zeta_{\wp}(f)$, and falsity $\varphi_{\wp}(f)$ membership functions. These functions are expressed by:

$$\wp = \{\langle f,\ \pi_{\wp}(f),\ \zeta_{\wp}(f),\ \varphi_{\wp}(f)\rangle \mid f \in F\}. \tag{1}$$

where these functions present real subsets of $[^-0, 1^+]$, $\pi_{\wp}(f)$, $\zeta_{\wp}(f)$, and $\varphi_{\wp}(f) : F \rightarrow [^-0, 1^+]$. The sum of three membership functions must satisfy:

$$^-0 \le \pi_{\wp}(f) + \zeta_{\wp}(f) + \varphi_{\wp}(f) \le 3^+, \quad \forall_f \in F \tag{2}$$

4.2. Type-2 neutrosophic set

The Type-2 neutrosophic numbers (T2NNs) were presented by Abdel-Basset et al. (2019), and extend the neutrosophic set developed by Smarandache (1998). The fundamental definitions and operations of T2NNs are defined by:

Definition 2 (Abdel-Basset et al., 2019). Let F be a universe of discourse and $N[0,1]$ be the set on $S[0,1]$. A T2NNs $\widehat{Z}$ in F is expressed by $\widehat{Z} = \{\langle f, \pi_{\widehat{Z}}(f), \zeta_{\widehat{Z}}(f), \varphi_{\widehat{Z}}(f)\rangle \mid f \in F\}$, where $\pi_{\widehat{Z}}(f) : F \to N[0, 1]$, $\zeta_{\widehat{Z}}(f) : F \to N[0, 1]$, and $\varphi_{\widehat{Z}}(f) : F \to N[0, 1]$.

A T2NNS $\breve{N}$ are represented by a truth $\pi_{\widehat{Z}}(f)$, indeterminacy $\zeta_{\widehat{Z}}(f)$, and falsity $\varphi_{\widehat{Z}}(f)$memberships and defined by $\pi_{\widehat{Z}}(x) = (\pi_{\pi_{\widehat{Z}}}(f), \pi_{\zeta_{\widehat{Z}}}(f), \pi_{\varphi_{\widehat{Z}}}(f))$, $\zeta_{\widehat{Z}}(x) = (\zeta_{\pi_{\widehat{Z}}}(f), \zeta_{\zeta_{\widehat{Z}}}(f), \zeta_{\varphi_{\widehat{Z}}}(f))$, and $\varphi_{\widehat{Z}}(x) = (\varphi_{\pi_{\widehat{Z}}}(f), \varphi_{\zeta_{\widehat{Z}}}(f), \varphi_{\varphi_{\widehat{Z}}}(f))$ belonging to the truth, indeterminacy, and falsity memberships of f in $\widehat{Z}$, and for every $f \in F$: $0 \le \pi_{\widehat{Z}}(f)^3 + \zeta_{\widehat{Z}}(f)^3 + \varphi_{\widehat{Z}}(f)^3 \le 3$.

A Type-2 neutrosophic number (T2NN) can be represented by $\widehat{Z} = \langle(\pi_{\pi_{\widehat{Z}}}(f), \pi_{\zeta_{\widehat{Z}}}(f), \pi_{\varphi_{\widehat{Z}}}(f)), (\zeta_{\pi_{\widehat{Z}}}(f), \zeta_{\zeta_{\widehat{Z}}}(f), \zeta_{\varphi_{\widehat{Z}}}(f)), (\varphi_{\pi_{\widehat{Z}}}(f), \varphi_{\zeta_{\widehat{Z}}}(f), \varphi_{\varphi_{\widehat{Z}}}(f))\rangle$.

Definition 3 (Abdel-Basset et al., 2019). Let two T2NNs $\widehat{Z}_1$ and $\widehat{Z}_2$ be expressed by:

$$\widehat{Z}_1 = \left\langle \left(\pi_{\pi_{\widehat{Z}_1}}(f), \pi_{\zeta_{\widehat{Z}_1}}(f), \pi_{\varphi_{\widehat{Z}_1}}(f)\right), \left(\zeta_{\pi_{\widehat{Z}_1}}(f), \zeta_{\zeta_{\widehat{Z}_1}}(f), \zeta_{\varphi_{\widehat{Z}_1}}(f)\right), \left(\varphi_{\pi_{\widehat{Z}_1}}(f), \varphi_{\zeta_{\widehat{Z}_1}}(f), \varphi_{\varphi_{\widehat{Z}_1}}(f)\right)\right\rangle,$$

and

$$\widehat{Z}_2 = \left\langle \left(\pi_{\pi_{\widehat{Z}_2}}(f), \pi_{\zeta_{\widehat{Z}_2}}(f), \pi_{\varphi_{\widehat{Z}_2}}(f)\right), \left(\zeta_{\pi_{\widehat{Z}_2}}(f), \zeta_{\zeta_{\widehat{Z}_2}}(f), \zeta_{\varphi_{\widehat{Z}_2}}(f)\right), \left(\varphi_{\pi_{\widehat{Z}_2}}(f), \varphi_{\zeta_{\widehat{Z}_2}}(f), \varphi_{\varphi_{\widehat{Z}_2}}(f)\right)\right\rangle$$

Some basic operations can be expressed by:

(a) Addition "$\oplus$"

$$\begin{aligned}\widehat{Z}_1 \oplus \widehat{Z}_2 = \Big\langle & \left(\pi_{\pi_{\widehat{Z}_1}}(f) + \pi_{\pi_{\widehat{Z}_2}}(f) - \pi_{\pi_{\widehat{Z}_1}}(f)\cdot\pi_{\pi_{\widehat{Z}_2}}(f)\right), \left(\pi_{\zeta_{\widehat{Z}_1}}(f) + \pi_{\zeta_{\widehat{Z}_2}}(f) - \pi_{\zeta_{\widehat{Z}_1}}(f)\cdot\pi_{\zeta_{\widehat{Z}_2}}(f)\right) \\ & , \left(\pi_{\varphi_{\widehat{Z}_1}}(f) + \pi_{\varphi_{\widehat{Z}_2}}(f) - \pi_{\varphi_{\widehat{Z}_1}}(f)\cdot\pi_{\varphi_{\widehat{Z}_2}}(f)\right), \\ & \left(\zeta_{\pi_{\widehat{Z}_1}}(f)\cdot\zeta_{\pi_{\widehat{Z}_2}}(f), \zeta_{\zeta_{\widehat{Z}_1}}(f)\cdot\zeta_{\zeta_{\widehat{Z}_2}}(f), \zeta_{\varphi_{\widehat{Z}_1}}(f)\cdot\zeta_{\varphi_{\widehat{Z}_2}}(f)\right), \\ & \left(\varphi_{\pi_{\widehat{Z}_1}}(f)\cdot\varphi_{\pi_{\widehat{Z}_2}}(f), \varphi_{\zeta_{\widehat{Z}_1}}(f)\cdot\varphi_{\zeta_{\widehat{Z}_2}}(f), \varphi_{\varphi_{\widehat{Z}_1}}(f)\cdot\varphi_{\varphi_{\widehat{Z}_2}}(f)\right)\Big\rangle,\end{aligned} \tag{3}$$

(b) Multiplication "$\otimes$"

$$\begin{aligned}\widehat{Z}_1 \otimes \widehat{Z}_2 = \Big\langle & \left(\pi_{\pi_{\widehat{Z}_1}}(f) + \pi_{\pi_{\widehat{Z}_2}}(f), \pi_{\zeta_{\widehat{Z}_1}}(f)\cdot\pi_{\zeta_{\widehat{Z}_2}}(f), \pi_{\varphi_{\widehat{Z}_1}}(f)\cdot\pi_{\varphi_{\widehat{Z}_2}}(f)\right), \\ & \left(\varphi_{\pi_{\widehat{Z}_1}}(f) + \varphi_{\pi_{\widehat{Z}_2}}(f) - \varphi_{\pi_{\widehat{Z}_1}}(f)\cdot\varphi_{\pi_{\widehat{Z}_2}}(f), \zeta_{\zeta_{\widehat{Z}_1}}(f) + \zeta_{\zeta_{\widehat{Z}_2}}(f) \right. \\ & \left. - \zeta_{\zeta_{\widehat{Z}_1}}(f)\cdot\zeta_{\zeta_{\widehat{Z}_2}}(f), \zeta_{\varphi_{\widehat{Z}_1}}(f) + \zeta_{\varphi_{\widehat{Z}_2}}(f) - \zeta_{\varphi_{\widehat{Z}_1}}(f)\cdot\zeta_{\varphi_{\widehat{Z}_2}}(f)\right), \\ & \left(\varphi_{\pi_{\widehat{Z}_1}}(f) + \varphi_{\pi_{\widehat{Z}_2}}(f) - \varphi_{\pi_{\widehat{Z}_1}}(f)\cdot\varphi_{\pi_{\widehat{Z}_2}}(f), \varphi_{\zeta_{\widehat{Z}_1}}(f) + \varphi_{\zeta_{\widehat{Z}_2}}(f) \right. \\ & \left. - \varphi_{\zeta_{\widehat{Z}_1}}(f)\cdot\varphi_{\zeta_{\widehat{Z}_2}}(f), \varphi_{\varphi_{\widehat{Z}_1}}(f) + \varphi_{\varphi_{\widehat{Z}_2}}(f) - \varphi_{\varphi_{\widehat{Z}_1}}(f)\cdot\varphi_{\varphi_{\widehat{Z}_2}}(f)\right)\Big\rangle,\end{aligned} \tag{4}$$

(c) Scalar multiplication

$$\begin{aligned}\Omega\widehat{Z} = \Big\langle & \left(1 - (1 - \pi_{\pi_{\widehat{Z}}}(f))^{\Omega}, 1 - (1 - \pi_{\zeta_{\widehat{Z}}}(f))^{\Omega}, 1 - (1 - \pi_{\varphi_{\widehat{Z}}}(f))^{\Omega}\right), \\ & \left((\zeta_{\pi_{\widehat{Z}}}(f))^{\Omega}, (\zeta_{\zeta_{\widehat{Z}}}(f))^{\Omega}, (\zeta_{\varphi_{\widehat{Z}}}(f))^{\Omega}\right), \\ & \left((\varphi_{\pi_{\widehat{Z}}}(f))^{\Omega}, (\varphi_{\zeta_{\widehat{Z}}}(f))^{\Omega}, (\varphi_{\tau_{\widehat{Z}}}(f))^{\Omega}\right)\Big\rangle,\end{aligned} \tag{5}$$

where $\Omega > 0$.

(d) Power

$$\begin{aligned}\widehat{Z}^{\Omega} = \Big\langle & \left((\pi_{\pi_{\widehat{Z}}}(f))^{\Omega}, (\pi_{\zeta_{\widehat{Z}}}(f))^{\Omega}, (\pi_{\varphi_{\widehat{Z}}}(f))^{\Omega}\right), \\ & \left(1 - (1 - (\zeta_{\pi_{\widehat{Z}}}(f)))^{\Omega}, 1 - (1 - \zeta_{\zeta_{\widehat{Z}}}(f))^{\Omega}, 1 - (1 - \zeta_{\varphi_{\widehat{Z}}}(f))^{\Omega}\right), \\ & \left(1 - (1 - \varphi_{\pi_{\widehat{Z}}}(f))^{\Omega}, 1 - (1 - \varphi_{\zeta_{\widehat{Z}}}(f))^{\Omega}, 1 - (1 - \varphi_{\tau_{\widehat{Z}}}(f))^{\Omega}\right)\Big\rangle.\end{aligned} \tag{6}$$

where $\Omega > 0$.

Definition 4 (Abdel-Basset et al., 2019). The score function $\mathrm{H}(\widehat{Z})$ of $\widehat{Z}$ is can be expressed by:

$$\begin{aligned}\mathrm{H}(\widehat{Z}) = \frac{1}{12}\langle 8 + (\pi_{\pi_{\widehat{Z}}}(f) + 2(\pi_{\zeta_{\widehat{Z}}}(f)) + \pi_{\varphi_{\widehat{Z}}}(f)) - (\zeta_{\pi_{\widehat{Z}}}(f) + 2(\zeta_{\zeta_{\widehat{Z}}}(f)) + \zeta_{\varphi_{\widehat{Z}}}(f)) \\ - (\varphi_{\pi_{\widehat{Z}}}(f) + 2(\varphi_{\zeta_{\widehat{Z}}}(f)) + \varphi_{\varphi_{\widehat{Z}}}(f))\rangle.\end{aligned} \tag{6}$$

The accuracy function $\mathrm{K}(\widehat{Z})$ of $\widehat{Z}$ is expressed by:

$$\mathrm{K}(\widehat{Z}) = \frac{1}{4}\langle(\pi_{\pi_{\widehat{Z}}}(f) + 2(\pi_{\zeta_{\widehat{Z}}}(f)) + \pi_{\varphi_{\widehat{Z}}}(f)) - (\varphi_{\pi_{\widehat{Z}}}(f) + 2(\varphi_{\zeta_{\widehat{Z}}}(f)) + \varphi_{\varphi_{\widehat{Z}}}(f))\rangle \tag{7}$$

The relations between $\mathrm{H}(\widehat{Z})$ and $\mathrm{K}(\widehat{Z})$ can be defined as follows:

1) If $\mathrm{H}(\widehat{Z}_1)\rangle\mathrm{H}(\widehat{Z}_2)$, then $\breve{N}_1$ is greater than $\widehat{Z}_2$, denoted by $\widehat{Z}_1 > \widehat{Z}_2$.
2) If $\mathrm{H}(\widehat{Z}_1) = \mathrm{H}(\widehat{Z}_2)$, and $\mathrm{K}(\widehat{Z}_1)\rangle\mathrm{K}(\widehat{Z}_2)$, then $\breve{N}_1$ is superior to $\widehat{Z}_2$, denoted by $\breve{N}_1 > \breve{N}_2$.
3) If $\mathrm{H}(\widehat{Z}_1) = \mathrm{H}(\widehat{Z}_2)$, and $\mathrm{K}(\widehat{Z}_1) = \mathrm{K}(\widehat{Z}_2)$, then $\widehat{Z}_1$ is equal to $\widehat{Z}_2$, denoted by $\widehat{Z}_1 = \widehat{Z}_2$.

4.3. T2NNs based RAFSI model

The RAFSI model (Žižović et al., 2020) was introduced to efficiently process group uncertain and unspecified information. This section provides a T2NNs based RAFSI model for choosing the most suitable alternatives for imposing electric vehicles. The RAFSI model has been successfully integrated into a variety of decision making problems (Alosta et al., 2021). The stages of the proposed T2NNs based RAFSI model are presented in Fig. 3.

The evaluation criteria, alternatives, and the group of experts are defined to construct the proposed model. The set $\wp_i = (\wp_1, \wp_2, \dots, \wp_n)$ having $i = 1, 2, \dots, n$ alternatives is assessed by $m$the decision criteria of the set $\varsigma_j = (\varsigma_1, \varsigma_2, \dots, \varsigma_m)$ having $j = 1, 2, \dots, m$ criteria using the group

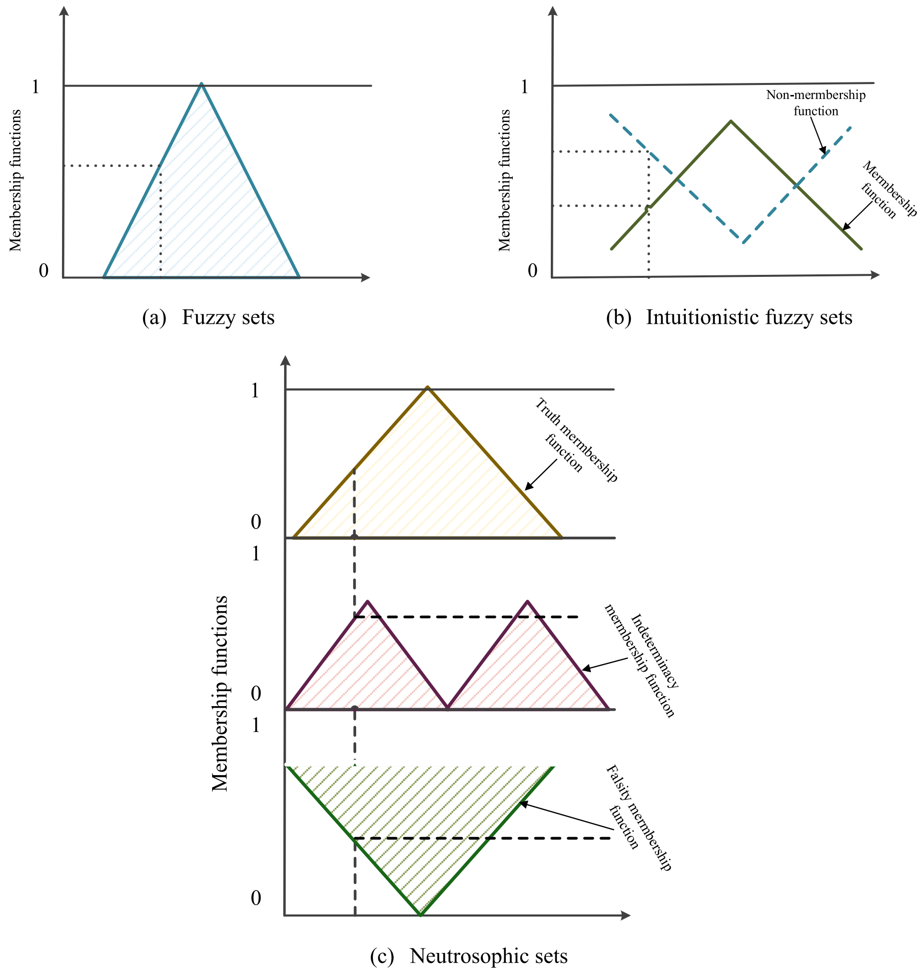

Fig. 2. Some fuzzy sets and their membership functions.

of experts $\eta_l = (\eta_1, \eta_2, \ldots, \eta_e)(\ell = 1, 2, \ldots, e)$. The linguistic terms are determined.

Step 1. Create the initial decision matrix $\widehat{X} = \left(\chi_{ij}\right)_{mxn}$ with T2NNs. Experts provides their opinions for each alternative regarding each decision criterion using linguistic terms.

$$\widehat{X} = \left(\chi_{ij}\right)_{nxm} = \begin{matrix} & \wp_1 & \wp_2 & \cdots\cdots & \wp_n \\ \varsigma_1 & \chi_{11} & \chi_{12} & \cdots\cdots & \chi_{1m} \\ \varsigma_2 & \chi_{21} & \chi_{22} & \cdots\cdots & \chi_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_m & \chi_{1n} & \chi_{2n} & \cdots\cdots & \chi_{nm} \end{matrix} \tag{8}$$

where $1 \le i \le n$ and $1 \le j \le m$.

Afterward, the linguistic terms in the initial matrix into the T2NNs decision matrix are converted.

Step 2. Calculate the score values $G = \left(g_{ij}\right)_{mxn}$ using T2NNs based on the initial matrix with the help of Eq. (6):

$$G = \left(g_{ij}\right)_{nxm} = \begin{matrix} & \wp_1 & \wp_2 & \cdots\cdots & \wp_n \\ \varsigma_1 & g_{11} & g_{12} & \cdots\cdots & g_{1m} \\ \varsigma_2 & g_{21} & g_{22} & \cdots\cdots & g_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_m & g_{1n} & g_{2n} & \cdots\cdots & g_{nm} \end{matrix} \tag{9}$$

where $1 \le i \le n$ and $1 \le j \le m$.

Step 3. Find the weights of the criteria by applying Eq. (6) with the help of experts opinions in terms of each criterion. The criteria weights are represented by $w_j = (j = 1, 2, \ldots, m)$.

Step 4. Find the ideal and anti-ideal values using γ_{ij} and Eq. (10). The experts provide two values α_{I_j} and α_{A_j}, where α_{I_j} denotes the ideal value of ς_j, and α_{A_j} is the anti-ideal value of ς_j. It can be seen that $\alpha_{I_j} > \alpha_{A_j}$ for benefit (max), and $\alpha_{I_j} < \alpha_{A_j}$ for cost (min) criteria.

$$\varsigma_j \in \begin{cases} \left(\alpha_{A_j}, \alpha_{I_j}\right), for \quad benefit \quad criteria \\ \left(\alpha_{I_j}, \alpha_{A_j}\right), for \quad cost \quad criteria \end{cases} \tag{10}$$

Step 5. Build the standardized decision matrix $T = \left(\tau_{ij}\right)_{nxm}$ using Eqs. (11)–(13). In order to make all the criteria of the initial decision

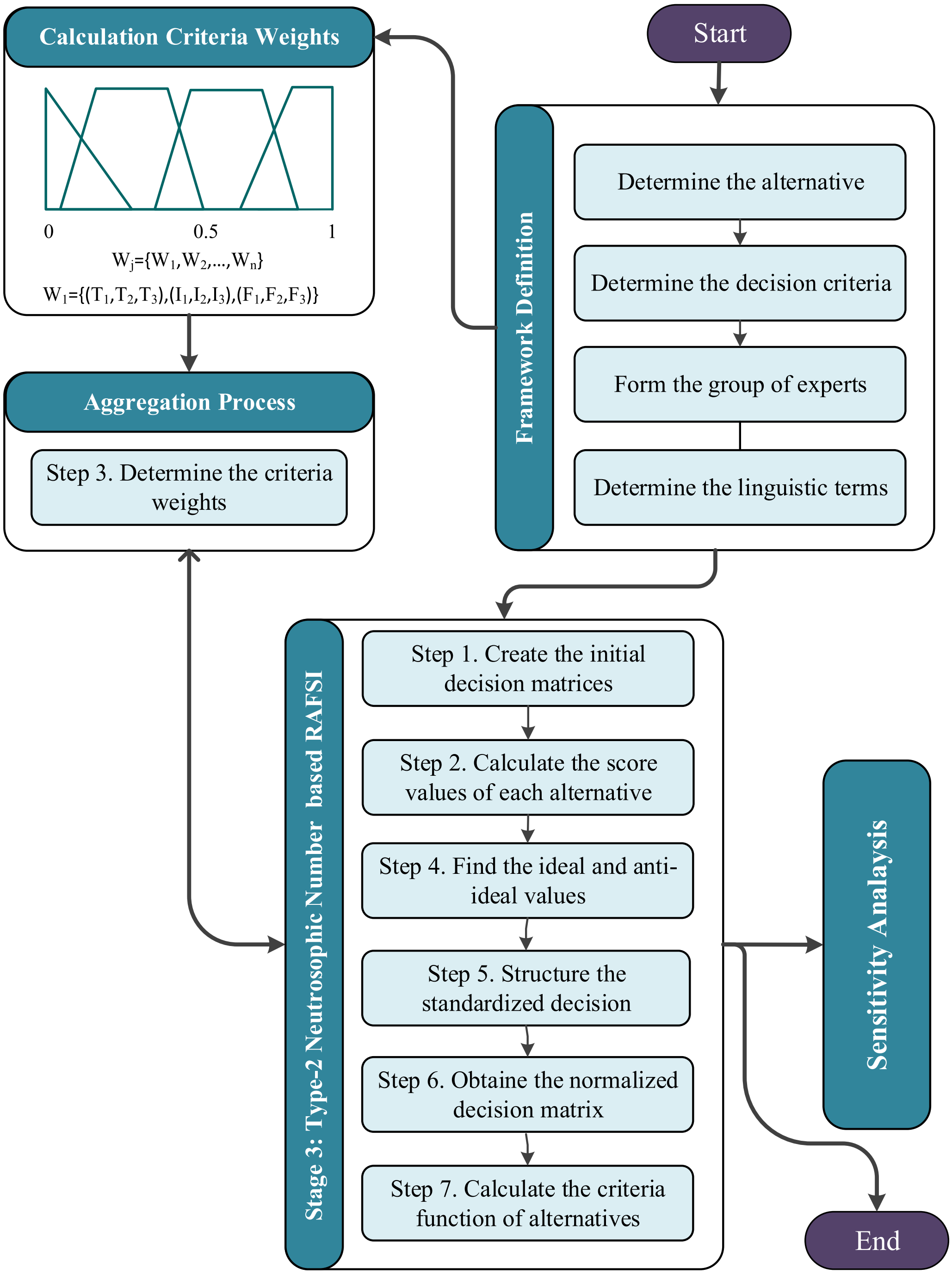

Fig. 3. The flowchart of the proposed T2NNs based RAFSI model.

matrix or to transfer them to the criteria range $[\mathfrak{I}_1, \mathfrak{I}_{2\lambda}]$, we are creating many sequences from the interval λ with $\lambda - 1$ points added between the highest and lowest values of the criteria interval. Later, the sub-intervals into the criteria interval are mapped with the help of functions Φ_1, Φ_2, Φ_3 and as illustrated in Fig. 4.

$$\mathfrak{I}_1 < \mathfrak{I}_2 \leq \mathfrak{I}_3 < \mathfrak{I}_4 \leq \mathfrak{I}_5 < \mathfrak{I}_6 \ldots \leq \mathfrak{I}_{2\lambda-1} \leq \mathfrak{I}_{2\lambda} \tag{11}$$

where $\Phi_d(x)$ denotes a function. It maps sub-intervals into the criteria interval $[\mathfrak{I}_1, \mathfrak{I}_{2\lambda}]$ using Eq. (12).

$$\Phi_d(x) = \frac{\mathfrak{I}_{2\lambda} - \mathfrak{I}_1}{\alpha_{I_j} - \alpha_{A_j}} \alpha_{ij} + \frac{\alpha_{I_j} \cdot \mathfrak{I}_1 - \alpha_{A_j} \cdot \mathfrak{I}_{2\lambda}}{\alpha_{I_j} - \alpha_{A_j}} \tag{12}$$

where $\mathfrak{I}_{2\lambda}$ and $\mathfrak{I}_1$ denotes the relations. α_{ij} is the value of the i-th alternative for the j-th criterion from the initial decision matrix.

$$T = (\tau_{ij})_{nxm} = \begin{array}{c} \\ \varsigma_1 \\ \varsigma_2 \\ \vdots \\ \varsigma_m \end{array} \begin{array}{c} \begin{array}{cccc} \wp_1 & \wp_2 & \ldots\ldots & \wp_n \end{array} \\ \begin{pmatrix} \tau_{11} & \tau_{12} & \ldots\ldots & \tau_{1m} \\ \tau_{21} & \tau_{22} & \ldots\ldots & \tau_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tau_{1n} & \tau_{2n} & \ldots\ldots & \tau_{nm} \end{pmatrix} \end{array} \tag{13}$$

Step 6. Find the normalized decision matrix with the help of Eqs. (14)–(17).

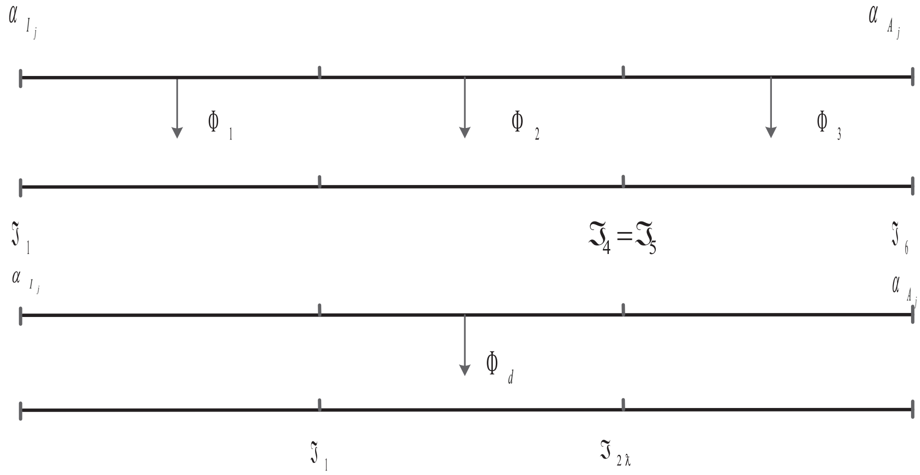

Fig. 4. Mapping of sub-intervals into the criteria interval.

$$\psi_{ij} = \begin{cases} \frac{\tau_{ij}}{2\beta}, & if \quad j \in max \\ \frac{\delta}{2\tau_{ij}}, & if \quad j \in min \end{cases} \tag{14}$$

β and δ represent the arithmetic and harmonic means, respectively. The β and δ values are found using Eqs. (15)–(16) for *min* and *max* sequence of the elements $\mathfrak{I}_{2\lambda}$ and $\mathfrak{I}_1$.

$$\beta = \frac{\mathfrak{I}_1 + \mathfrak{I}_{2\lambda}}{2} \tag{15}$$

$$\delta = \frac{2}{\frac{1}{\mathfrak{I}_1} + \frac{1}{\mathfrak{I}_{2\lambda}}} \tag{16}$$

Afterward, the values are normalized with the help of Eq. (17).

$$\aleph = (\varepsilon_{ij})_{nxm} = \begin{matrix} & \wp_1 & \wp_2 & \cdots\cdots & \wp_n \\ \varsigma_1 & \varepsilon_{11} & \varepsilon_{12} & \cdots\cdots & \varepsilon_{1m} \\ \varsigma_2 & \varepsilon_{21} & \varepsilon_{22} & \cdots\cdots & \varepsilon_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_m & \varepsilon_{1n} & \varepsilon_{2n} & \cdots\cdots & \varepsilon_{nm} \end{matrix} \tag{17}$$

where $\varepsilon_{ij} \in [0, 1]$ is the elements of $\aleph$.

Step 7. Obtain the criteria function of each alternative θ_i using Eq. (18).

$$\theta_i = w_1\varepsilon_{i1} + w_2\varepsilon_{i2} + \cdots + w_j\varepsilon_{ij} = \sum_{j=1}^{m} \omega_j \varepsilon_{ij} \tag{18}$$

Then, rank the alternatives in decreasing order according to the values of θ_i.

5. Case study

To simulate the decision-making process in implementing EVs where the electricity is mostly produced by fossil fuels, we consider a scenario that includes three alternatives: One alternative is to focus on the renewable energy development first, before starting to finance the implementation of EVs; another alternative is to focus on the imposing the EVs by directing the available financial resources to the process; a third alternative is to maintain the status quo for a while and to regulate the existing system before transforming the whole system. In choosing the alternative to implement EVs, we build up a set of 12 criteria based on literature and experts' opinions. Different outcomes may occur in different countries because of the importance of the 12 criteria. The case scenario is tested in Turkey through questionnaires by Turkish experts from academia and the transportation sector. The novel method that we used to solve the decision-making problem is tested against two other already existing fuzzy methods.

Table 1
The list of the alternatives and evaluation criteria for imposing electric vehicles in developing countries.

Main-criteria	Sub-criteria	Types
Social and Political (MC_1)		
C_1	Social acceptance	Benefit
C_2	Reduced political support	Cost
C_3	Enhanced social inclusiveness	Benefit
Technical Readiness Aspect (MC_2)		
C_4	Need for the existence of technical infrastructure	Cost
C_5	Need for the existence of preventive maintenance services.	Cost
C_6	Availability of supply chain of physical capital to implement the alternative	Benefit
Financial and Economic Aspect (MC_3)		
C_7	The need for availability of the financial support	Cost
C_8	Job creation	Benefit
C_9	The enhanced macroeconomic environment of the country	Benefit
Image in International Community Aspect (MC_4)		
C_{10}	Requirement for the adaptation rate of the industries to the regulations	Cost
C_{11}	The need for Readiness and resilience to climate change	Cost
C_{12}	Enhanced global image of the government	Benefit

Table 2
The linguistic scale for evaluation ratings of the criteria (Abdel-Basset et al., 2019).

Linguistic variables/terms	T2NN
Weakly important (WI)	<(0.20, 0.30, 0.20), (0.60, 0.70, 0.80), (0.45, 0.75, 0.75)>
Equal important (EI)	<(0.40, 0.30, 0.25), (0.45, 0.55, 0.40), (0.45, 0.60, 0.55)>
Strong important (SI)	<(0.50, 0.55, 0.55), (0.40, 0.45, 0.55), (0.35, 0.40, 0.35)>
Very strongly important (VSI)	<(0.80, 0.75, 0.70), (0.20, 0.15, 0.30), (0.15, 0.10, 0.20)>
Absolutely important (AI)	<(0.90, 0.85, 0.95), (0.10, 0.15, 0.10), (0.05, 0.05, 0.10)>

Table 3
The linguistic scale for evaluation ratings of alternatives (Abdel-Basset et al., 2019).

Linguistic variable	Type-2 neutrosophic number
Very Bad (VB)	<(0.20, 0.20, 0.10), (0.65, 0.80, 0.85), (0.45, 0.80, 0.70)>
Bad (B)	<(0.35, 0.35, 0.10), (0.50, 0.75, 0.80), (0.50, 0.75, 0.65)>
Medium Bad (MB)	<(0.50, 0.30, 0.50), (0.50, 0.35, 0.45), (0.45, 0.30, 0.60)>
Medium (M)	<(0.40, 0.45, 0.50), (0.40, 0.45, 0.50), (0.35, 0.40, 0.45)>
Medium Good (MG)	<(0.60, 0.45, 0.50), (0.20, 0.15, 0.25), (0.10, 0.25, 0.15)>
Good (G)	<(0.70, 0.75, 0.80), (0.15, 0.20, 0.25), (0.10, 0.15, 0.20)>
Very Good (VG)	<(0.95, 0.90, 0.95), (0.10, 0.10, 0.05), (0.05, 0.05, 0.05)>

5.1. Proposed methodology results

Three alternatives are defined under four main and twelve sub-criteria, and these criteria are used to select an alternative to imposing electric vehicles in developing countries with the help of six experts. The list of the alternatives and criteria is reported in Table 1.

The linguistic ratings for the evaluation of the alternatives and weighting of the criteria are given in Tables 2 and 3.

The twelve criteria are evaluated by six experts using the linguistic terms given in Table 2. The expert opinions of each alternative regarding the criteria using linguistic terms given in Table 3 are collected. The evaluation results are reported in Tables 4 and 5.

Step 1. The linguistic assessments of alternatives are transformed into the corresponding Type-2 neutrosophic numbers using Table 5 with the help of Table 3 and structured the initial decision matrix.
Step 2. The score values of each alternative concerning are obtained using Eqs. (8) and (8), and are presented in Table 6.

Step 3. Applying Eq. (6), the weight coefficient of the criteria is found with the help of Table 4. The weights of each criterion are illustrated in Fig. 5 and presented in Table 7.

Step 4. The ideal α_{A_j} and anti-ideal α_{I_j} values for each criterion are defined using Eq. (10) and Table 6 and are listed in Table 8.

Step 5. The standardized normalized decision matrix is obtained using Eqs. (11)–(13) and Tables 6 and 8. The values of the matrix are presented in Table 9.

Step 6. The normalized matrix of each alternative is found using Eqs. (14)–(17) and Table 9, and are presented in Table 10.

Step 7. The overall values of each alternative are obtained using Eq. (18) and Table 10. These values are given in Table 11. The ranking of the alternative by θ_i in decreasing order is listed in Table 11 as

Table 6
The score values of each alternative regarding criteria.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.878	0.834	0.832	0.800	0.780	0.888
A_2	0.893	0.847	0.855	0.742	0.758	0.887
A_3	0.819	0.742	0.857	0.890	0.896	0.816
Type	Max	Min	Max	Min	Min	Max

Alternatives	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.750	0.886	0.895	0.805	0.742	0.879
A_2	0.800	0.893	0.896	0.778	0.780	0.889
A_3	0.778	0.769	0.874	0.733	0.758	0.831
Type	Min	Max	Max	Min	Min	Max

Table 4
The linguistic assessments of the criteria regarding criteria by experts.

Experts	Criteria											
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
E_1	VSI	VSI	AI	AI	SI	SI	VSI	EI	AI	EI	VSI	SI
E_2	EI	VSI	SI	VSI	SI	AI	AI	SI	VSI	VSI	AI	SI
E_3	VSI	VSI	EI	AI	EI	AI	VSI	VSI	AI	VSI	VSI	SI
E_4	AI	VSI	WI	VSI	EI	AI	AI	VSI	VSI	SI	VSI	EI
E_5	VSI	EI	EI	VSI	VSI	AI	VSI	VSI	AI	VSI	SI	SI
E_6	SI	AI	EI	VSI	VSI	AI	AI	EI	SI	SI	VSI	SI

Table 5
The linguistic assessments of the alternatives regarding criteria by experts.

Alternatives	Experts	Criteria											
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	E_1	G	B	VG	B	VB	VG	B	G	VG	B	VB	VG
	E_2	G	MG	B	B	M	MG	VB	G	MG	B	VB	G
	E_3	G	MB	M	MG	MB	G	VB	G	G	MB	B	VG
	E_4	G	M	M	M	B	MG	B	VG	VG	B	VB	VG
	E_5	G	MB	M	MB	M	MG	VB	G	VG	B	VB	VG
	E_6	MG	G	MB	VB	VB	VG	VB	MG	MB	MG	VB	VG
A_2	E_1	G	VB	G	VB	VB	VG	VB	VG	VG	VB	MG	VG
	E_2	VG	G	MG	VB	VB	MG	MG	G	MG	MB	B	G
	E_3	G	G	MB	B	B	G	B	VG	VG	VB	B	G
	E_4	VG	MB	M	VB	VB	VG	VB	VG	VG	VB	VB	VG
	E_5	VG	MB	MG	VB	MB	G	B	VG	G	VB	B	VG
	E_6	G	G	G	VB	VB	B	G	MG	B	G	VB	VG
A_3	E_1	VG	VB	M	G	G	M	G	B	G	VB	B	M
	E_2	VB	VB	VG	VG	VG	VB	B	B	G	VB	MB	M
	E_3	B	B	M	G	G	B	B	B	MG	VB	VB	MG
	E_4	MB	VB	M	VG	VG	VB	VB	VB	VG	VB	VB	M
	E_5	M	VB	M	B	MB	MG	VB	M	MG	VB	VB	MG
	E_6	B	VB	VG	G	VG	VG	VB	VB	B	VB	VB	MG

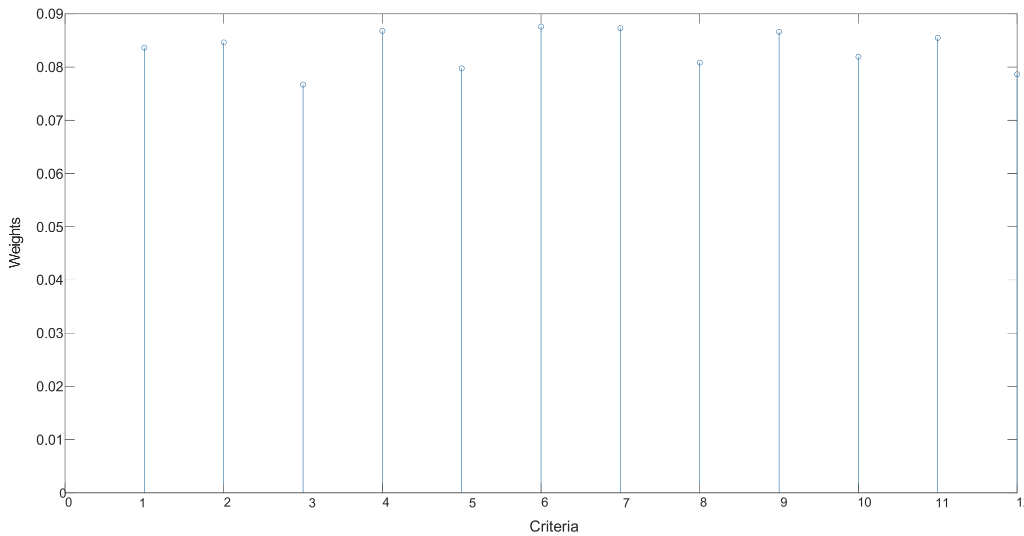

Fig. 5. The weights of each criterion.

Table 7
Weighting coefficients of each criterion.

	Aggregated T2NNs of the criteria	Score values	Normalized values
C_1	<(0.68, 0.65, 0.63), (0, 0, 0), (0, 0, 0)>	0.885	0.084
C_2	<(0.73, 0.68, 0.66), (0, 0, 0), (0, 0, 0)>	0.895	0.085
C_3	<(0.47, 0.43, 0.41), (0, 0, 0), (0, 0, 0)>	0.811	0.077
C_4	<(0.78, 0.75, 0.75), (0, 0, 0), (0, 0, 0)>	0.918	0.087
C_5	<(0.56, 0.53, 0.5), (0, 0, 0), (0, 0, 0)>	0.843	0.080
C_6	<(0.78, 0.76, 0.81), (0, 0, 0), (0, 0, 0)>	0.926	0.088
C_7	<(0.79, 0.76, 0.78), (0, 0, 0), (0, 0, 0)>	0.923	0.087
C_8	<(0.61, 0.56, 0.52), (0, 0, 0), (0, 0, 0)>	0.855	0.081
C_9	<(0.76, 0.74, 0.76), (0, 0, 0), (0, 0, 0)>	0.916	0.087
C_{10}	<(0.62, 0.6, 0.57), (0, 0, 0), (0, 0, 0)>	0.867	0.082
C_{11}	<(0.74, 0.71, 0.7), (0, 0, 0), (0, 0, 0)>	0.904	0.085
C_{12}	<(0.48, 0.51, 0.5), (0, 0, 0), (0, 0, 0)>	0.832	0.079

ranked in $\wp_2 > \wp_1 > \wp_3$. It can be seen that $\wp_2$ is the most suitable alternative.

5.2. Validation of the results

In this section, the results of the proposed T2NNs based RAFSI model are tested and validated by comparing it with T2NNs based TOPSIS (Abdel-Basset et al., 2019) and T2NN based CoCoSo (Deveci et al., 2022). The ranking results of each methodology are shown in Fig. 6, and are reported in Table 12. The ranking of alternatives obtained from each methodology is $A_2 > A_1 > A_3$. Each T2NNs based model obtained A_2 to be the most suitable alternative while A_3 is the less suitable alternative for the three methodologies.

6. Results and discussion

All the methods verified the same solution that the implementation of EVs directly is best to start immediately although it may cause a higher consumption of fossil fuels in the short run. The second alternative has the highest rank, while the first alternative is the second-best

Table 9
The standardized normalized decision matrix.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	4.882	4.342	2.578	3.488	3.009	5.418
A_2	5.633	4.679	3.762	2.041	2.457	5.365
A_3	1.933	2.041	3.863	5.757	5.889	1.807
Type	Max	Min	Max	Min	Min	Max

Alternatives	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	2.249	5.638	5.750	3.620	3.082	4.959
A_2	3.491	5.825	5.783	2.942	5.019	5.452
A_3	2.942	2.733	4.678	1.833	3.914	2.551
Type	Min	Max	Max	Min	Min	Max

Table 10
The normalized matrix.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.697	0.197	0.368	0.246	0.285	0.774
A_2	0.805	0.183	0.537	0.420	0.349	0.766
A_3	0.276	0.420	0.552	0.149	0.146	0.258

Alternatives	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.381	0.805	0.821	0.237	0.278	0.708
A_2	0.245	0.832	0.826	0.291	0.171	0.779
A_3	0.291	0.390	0.668	0.468	0.219	0.364

Table 11
The overall values of each alternative.

Alternatives	θ_i	Rank
A_1	0.484	2
A_2	0.515	1
A_3	0.349	3

Table 8
The set of ideal and anti-ideal values.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Ideal	0.9	0.7	0.9	0.7	0.7	0.9	0.7	0.9	0.9	0.7	0.7	0.9
Anti-ideal	0.8	0.9	0.8	0.9	0.9	0.8	0.9	0.7	0.8	0.9	0.8	0.8

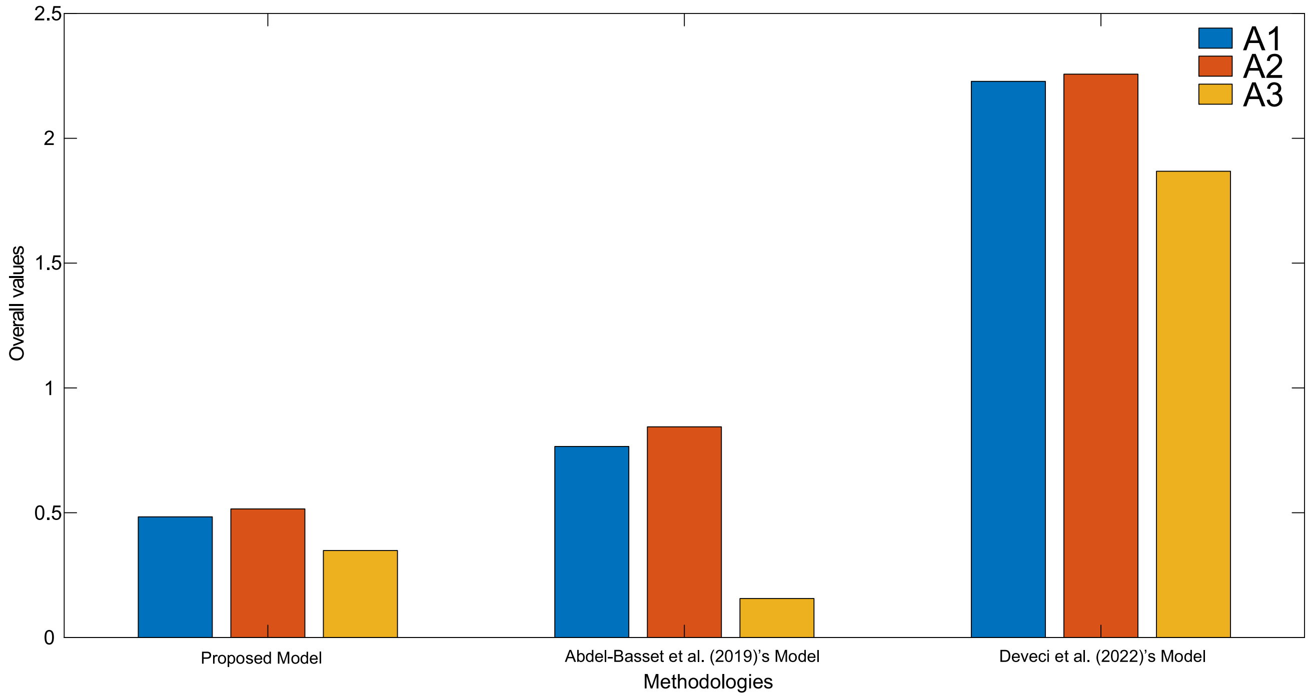

Fig. 6. The comparison of the proposed model with existing T2NN based MCDM models.

Table 12
The ranking results of comparative analysis.

	Proposed model		Abdel-Basset et al. (2019)		Deveci et al. (2022)	
	Overall values	Rank	Overall values	Rank	Overall values	Rank
A_1	0.484	2	0.766	2	2.228	2
A_2	0.515	1	0.844	1	2.257	1
A_3	0.349	3	0.156	3	1.868	3

option, and the third one is the least favorable.

The results put forward that even in the case where energy production is highly dependent on fossil fuels, the investments should be directed to the implementation of EVs at the first hand. Although environmental concerns are the prior reasons behind the support given to the development of EVs, the benefits can be agreed to be utilized in the long run.

The investments that are made to improve renewable energy production are highly important not just for the transportation industry but for the whole economy. It is inevitable to accelerate renewable energy production for all the countries, taken the depleting fossil fuel resources of the world. However, the results of the model imply that it should be already an ongoing process while societies are adapting themselves to the new environment-friendly technologies socially, culturally, and economically.

The regulations can be temporary solutions in transition periods to encourage stakeholders to relinquish traditional systems and internalize environment-friendly technologies. Yet, the results hint at the direct implementation of the new technology is significantly prioritized for the model.

As a result, the findings of the model suggest that the direct imposition of EVs is prioritized over the other alternatives that may temporarily suspend the implementation process in developing countries. Even if the short-run costs may exceed the short-run benefits, the environmental concerns are serious enough so that the expected long-run benefits override the short-run losses.

7. Policy implications

The enormous increase in energy demand since the beginning of industrialization caused the Western world finally to search for non-fossil energy sources. After all, the reallocation trials of the fossil fuel resources of the world had led to drastic consequences such as the world wars or the Cold War period. The recent urges to take climate action accelerated the efforts in producing energy from renewables. Unfortunately, the developing world is not ready to invest in renewable energy resources, yet. We are all in the same boat, and the countries, whether developed or not, have to take climate action. However, the implementation of environment-friendly solutions, such as the use of EVs, can create some additional problems due to the lack of required infrastructure. In this study, we analyze a decision-making process for implementing EVs in a developing country in which energy production is mainly from fossil fuels. If it is a fact that the environmental benefits of the new technology can be only utilized in the long run, could it be still in the best interest of a country to implement it directly? The results of the model give a significant positive answer to that question.

The results imply that alternatives that may improve the short-run environmental benefits of the use of EVs are seen as the delaying of the implementation process. Renewable energy production is highly important, and must be done but it should be prioritized over the direct implementation process.

The implementation of EVs is already a challenging process. It requires a gentle planning procedure that includes macro-and microeconomic concerns. The financial investments, which are economy-wide, are supposed to be supported by the government. Studies show that manufacturers of EVs as well as the other stakeholders in the automotive industry are better to be financially supported at the first stages of the transition period (Gao and Zhang, 2022) However, excessive subsidies may cause uncontrollable imperfections and market failures (Ye et al., 2021). In other words, careful industrial policies have to be designed and then practiced. Moreover, the consumers' preferences may tend to stick to traditional vehicles depending on the lifestyle and demography of the country (Huang et al., 2021b; Bas et al., 2021). Therefore, first, consumer tastes should be tested and then strong promotions should be provided to the consumers to convince them to use EVs. Even in some cases, traditional vehicles can be adapted to new technologies, such as e-rickshaws in India (Singh et al., 2021). This kind of hybrid solution that brings traditional and new technology together can be much more easily internalized. Yet, it may take some time for consumers to be convinced about the benefits of EVs. From both the consumer and producer sides, there are various obstacles to solve. Industry-wide transformation of the business models may be required.

The implementation of EVs also transforms a lot of other industries other than automotive, such as the transportation networks and the logistics sector (Monios and Bergqvist, 2020). Similarly, the vertical markets are also directly affected by the transition. The production of power systems to charge EVs, or hydrogen production, requires huge investments that cannot be financed by the government's budgets. Therefore, it may take some time before authorities to come up with an appropriate financing system such as a public-private partnership (Sheng et al., 2020).

All in all, the implementation process of EVs is not easy and takes time. The results that we obtained in this study show that the experts are aware of the process. In a developing country that is ready to use the opportunity window opened by a newly introduced technology, suspension of the process is not a favorable option against all the odds. Indeed, the short-run environmental benefits of EVs can be increased through further use of circular economy concepts such as recycling power batteries (Chen et al., 2022). Moreover, the economic and environmental long-run benefits are both so strong that it is worth taking the short-run losses.

8. Conclusion

In this study, we explore the decision-making process for implementing EVs in a developing country where energy is mainly produced from fossil fuels. A scenario is developed to analyze the decision-making process, where three alternatives are considered. The alternatives are to focus on the timing of implementation of the EVs considering the short-run environmental costs can exceed the benefits of EVs. The results of the model show that even though fossil fuel use may increase in the short-run period, the direct implementation of the new system is prioritized. The policy implications of the results are discussed in this study. The long-run benefit expectations are so strong that the short-run losses can be tolerated. Moreover, the implementation process is already challenging, and it requires a specific amount of time and financial investment. Renewable energy production should be invested but it shouldn't slow down the direct implementation of EVs.

Here, we consider only the timing of the implementation process of EVs taking the probable short-run losses into account. When electricity is produced by fossil fuels, such losses are inevitable. The policy-making process regarding the adaptation process is a fertile research area. How the technological acceptance pace of society can be evaluated in the process is also an interesting dimension to be included in a model. Also, different agent-based models can be considered in the decision-making process (Mehdizadeh et al., 2022). Another future work would be contributing to the strategic management literature by studying how the innovation policy mixes can be used for the implementation of EVs (Phirouzabadi et al., 2022). The limitations of the study are that an expert cannot evaluate an alternative equally in terms of all criteria. Therefore, the criteria can be grouped under the main criteria, and the decision-making model can be run by giving weight to the experts for these groups.

CRediT authorship contribution statement

Ilgin Gokasar: Conceptualization, Data curation, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Muhammet Deveci:** Methodology, Software, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Mehtap Isik:** Conceptualization, Data curation, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Tugrul Daim:** Supervision, Validation, Writing – original draft, Writing – review & editing. **Aws A. Zaidan:** Supervision, Validation, Writing – original draft, Writing – review & editing. **Florentin Smarandache:** Supervision, Validation, Writing – original draft, Writing – review & editing.

Data availability

The data that has been used is confidential.

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Ilgin Gokasar received the B.S. degree in civil engineering from Boğaziçi University, Istanbul, Turkey, in 2000, and the M.S. and Ph.D. degrees in civil engineering (intelligent transportation systems) from Rutgers University, NJ, USA, in 2003 and 2006, respectively. She is currently an Associate Professor in the Department of Civil Engineering, Bogazici University. She is also the Founder and the Director of the BOUN-ITS and Mobility Laboratories. Her research interests include Intelligent Transportation Systems, Traffic Safety, Ramp Metering, Real-Time Traffic Control, Incident Management, Work Zone Traffic Management, Advanced Public Transportation Systems, Traffic Flow Modeling and Simulation, Connected/Autonomous Vehicles, EV, Micromobility, mobility as a service (MAAS), Smart and Sustainable Transportation Systems Effects of Climate Change, Resilience of Transportation Systems, Circular Economy Implementations in Transportation Engineering, The Use of Big Data to Address Challenges in Mobility, Safety, Equity, Sustainability in Multimodal Transportation Systems, Airport Ground Access and Egress Modeling, Travel Behavior.

Muhammet Deveci is an Honorary Senior Research Fellow with the Bartlett School of Sustainable Construction, University College London, UK, and he is a Visiting Professor at Royal School of Mines in the Imperial College London, London, UK. He worked as a Visiting Researcher and Postdoctoral Researcher, in 2014–2015 and 2018–2019, respectively, with the School of Computer Science, University of Nottingham, Nottingham, U.K. Dr. Deveci has published 85 papers in journals indexed by SCI/SCI-E papers at reputable venues, as well as >23 contributions in International Conferences related to his areas. Dr. Deveci is currently an Editorial Board Member of Applied Soft Computing, and he has worked as a guest editor for many international journals such as IEEE Transactions on Fuzzy Systems (TFS), Applied Soft Computing, Annals of Operations Research, Sustainable Energy Technologies and Assessments, Journal of Petroleum Science and Engineering, and International of Journal of Hydrogen Energy (IJHE). His research focuses on computational intelligence, handling of uncertainty, fuzzy sets and systems, fuzzy decision making, decision support systems, modeling and optimization, and their hybrids, applied to complex real-world problems such as climate change, renewable energy, metaverse, and sustainable transport, urban mobility, autonomous vehicles, digitalization, and circular economy, and so on. Dr. Deveci has published in reputable SCI-indexed Top Journals including IEEE Transactions on Fuzzy Systems, IEEE Transactions on Transportation Electrification, IEEE Transactions on Engineering Management, IEEE Transactions on Intelligent Transportation Systems, Experts Systems with Applications, Engineering Applications of Artificial Intelligence, Knowledge Based System, Information Sciences, Applied Soft Computing, Soft Computing, IEEE Access, Computers and Industrial Engineering, Applied Energy, Annals of Operation Research, Renewable Energy, Energy, Sustainable Cities and Society, Journal of Cleaner Production, and so on. According to Scopus and Stanford University, he is Among World's Top 2 % Scientists in the field of Artificial Intelligence.

Mehtap Isik has BSc degree in Mathematics, MA and PhD degrees in Economics from Bogazici University. She had worked as a Risk analyst at Citibank, Istanbul. Later, she joined the Department of International Trade as a full-time faculty member. Her research interests include microeconomic theory, network theory, international economics and development, political economy and environmental economics. She is also lecturing in these subjects at Department of International Trade and Institute of Social Sciences, Bogazici University.

Tugrul Daim is the Associate Director of National Academic Center of Excellence for Cybersecurity and a Fulbright Scholar. He leads a research group on Technology Evaluations and Research Applications. His research group has been supported by National Science Foundation, National Security Agency, Department of Defense, National Cooperative Highway Research Program, Energy Trust of Oregon, US Dept of Energy, Bonneville Power Administration, Northwest Energy Efficiency Alliance, EPRI, Biotronik, Ford Motor Corporation, Intel Corporation, US Aid, Fullbright, Saudi Arabia Cultural Mission, Libyan Ministry of Education, CAPES Brazil, Maseeh Foundation, Oregon BEST, TUBITAK Turkey, Chinese Scholarship Council, FAPESP Brazil, Oregon Health and Science University, and University of Bremen. Professor Daim has published over 250 refereed journal papers, >20 special issues and >25 books. Prior to joining PSU, Professor Daim worked at Intel Corporation for over a decade in varying management roles including the management of product and technology development. During his tenure at PSU, he had worked very closely with Bonneville Power Administration to develop a research and technology management framework run by technology roadmaps.

Aws A. Zaidan is an Associate Professor at the British University in Dubai, Faculty of Engineering & IT. In 2014, I completed my PhD degree in Computer Engineering from the Multimedia University, Malaysia. Dr. Aws research is multidisciplinary that focuses on intensive analysis and decision based artificial intelligence and data science, with a focus on two fundamental concepts; (A) multi-attributes decision-making and optimization techniques (B) traditional machine leaning and deep-learning techniques. By relying on this, My research mainly focused on different disciplines of software intelligence in the basis of two directions (soft computing) and (operational research). Dr. Aws published >200 research papers in many international journals indexing at ISI WOS >95 % in Q1: top 60 % of journals in that subject category, and [CORE2022 Rank: A & A*], many of them appeared in IEEE Transactions/Elsevier, 19 Intellectual Property (Patents), and inventor on 4 theories at AI and Data Science. Dr. Aws research work over the years has contributed to the development of several intelligence commercial systems. I consulted for the national decision making data centre. Malaysian center of research and development division (E-Science Fund), and more recently on AI and data science.

Florentin Smarandache is a professor of mathematics at the University of New Mexico, United States. He got his MSc in Mathematics and Computer Science from the University of Craiova, Romania, PhD in Mathematics from the State University of Kishinev, and Postdoctoral in Applied Mathematics from Okayama University of Sciences, Japan. He is the founder of neutrosophy (generalization of dialectics), neutrosophic set, logic, probability and statistics since 1995 and has published hundreds of papers and books on neutrosophic physics, superluminal and instantaneous physics, unmatter, quantum paradoxes, absolute theory of relativity, redshift and blueshift due to the medium gradient and refraction index besides the Doppler effect, paradoxism, outerart, neutrosophy as a new branch of philosophy, Law of Included Multiple-Middle, multispace and multistructure, hypersoft set, degree of dependence and independence between neutrosophic components, refined neutrosophic set, neutrosophic over-under-off-set, plithogenic set/logic/probability/statistics, neutrosophic triplet and duplet structures, quadruple neutrosophic structures, extension of algebraic structures to NeutroAlgebras and AntiAlgebras, NeutroGeometry & AntiGeometry, Dezert-Smarandache Theory and so on to many peer-reviewed international journals and many books and he presented papers and plenary lectures to many international conferences around the world.