



# Sustainability assessment of optimal location of electric vehicle charge stations: a conceptual framework for green energy into smart cities

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## Abstract

Electric vehicles (EVs) have achieved a great deal of success, indicating that the motor industry will soon be emission-free. They run on electricity stored in batteries, which their drivers can recharge using an external source of electricity. Therefore, the development of an infrastructure for charging EVs has become a necessity. In this paper, a real case study in Zagazig, Egypt, for evaluating, operating, and determining the most sustainable location for an EV charging station is presented. Identifying such a location is a complex task that requires considering many influencing factors and their sub-factors. Consequently, a general evaluation system that includes six key factors, in addition to nineteen sub-factors, has been developed. A multi-criteria decision-making (MCDM) approach is applied to deal with this problem. The neutrosophic theory with type-2 neutrosophic numbers (T2NNs) and a type-2 neutrosophic number weighted averaging (T2NNWA) operator are used to combine expert and specialized views since they are ambiguous and uncertain. Firstly, the Decision-making Trial and Evaluation Laboratory (DEMATEL) method is applied to prioritize key factors and sub-factors. Then, the Complex Proportional Assessment (COPRAS) technique selects six sustainable sites for EV charging stations. Also, comparison and sensitivity evaluations verify the approach's reliability, strength, stability, and performance. Finally, this article provides good information for policymakers and the results of the case study indicate that the economic factor is the most important factor in selecting the optimal location followed by the technical factor.

**Keywords** Sustainable · Electric vehicle charging station · Uncertainty · Decision-making trial and evaluation laboratory · Complex proportional assessment

## Abbreviations

EV	Electric vehicles
MCDM	Multi-criteria Decision-making
T2NNs	Type-2 neutrosophic numbers
T2NNWA	Type-2 neutrosophic number weighted averaging
DEMATEL	Decision-making trial and evaluation laboratory
COPRAS	Complex proportional assessment

Extended author information available on the last page of the article

DEA	Data envelopment analysis
MULTIMOORA	Multi-objective optimization based on ratio analysis with full multiplicative form
MOORA	Multi-objective optimization on the basis of ratio analysis
LEW	Linguistic entropy weight
FAD	Fuzzy axiomatic design
AHP	Analytical hierarchical process
EWM	Entropy weight method
BWM	Best-worst method
GRA	Gray relation analysis
GIS	Geographic information system
TOPSIS	Technique for order of preference by similarity to ideal solution
ARAS	Additive ratio assessment
WSM	Weighted sum model
MABAC	Multi-attributive border approximation area comparison
ISM	Interpretive structural modeling
CSC	Circular supply chain
ANP	Analytical network process
CRITIC	Criteria importance through intercriteria correlation

## 1 Introduction

In 2015, the United Nations (UN) member nations endorsed the Sustainable Development Goals (SDGs), commonly referred to as the Global Goals, to establish a more peaceful and affluent society by 2030 (Nundy et al., 2021). Therefore, road vehicle electrification is essential to control environmental challenges (Ghosh, 2020). Electric vehicles (EVs) are considered the most important alternatives to conventional vehicles that rely on traditional fuels as energy sources because they contribute to creating a clean environment by avoiding the effects of carbon and its derivatives (Zhao et al., 2021). With increasing problems caused by cars using fossil fuels, it has become necessary for better forms of energy to be found in light of the mounting rise in environmental pollution and the trend toward alternative energy (de Souza et al., 2018). In this regard, governments and car manufacturers as well as development companies are seeking safe alternatives to current well-known car models, which operate using internal combustion engines and depend on petroleum derivatives, such as hybrid vehicles that consume less fuel (Das et al., 2020) in this era of fully electric cars. Also, as EVs are known to be very efficient and consume less energy to make energy than traditional fuels, they are environmentally friendly, with their concept due to the global shortage of fuel reserves (Kobashi et al., 2020). EVs rely entirely on electricity stored in the battery pack to move the wheels. Also, the driver of the EV can recharge the battery using an external source of electricity. Plug-in hybrid vehicles have a petrol or diesel engine as well as an electric motor, and the battery can be recharged in the same way. EVs are steadily moving in the direction of replacing traditional gasoline-powered vehicles and playing a bigger role in helping to protect the environment by reducing transportation's carbon footprint (Ma et al., 2021).

In recent years, the electric car industry has developed remarkably as the companies that produce them have invented vehicles with high specifications that do not require any type of traditional fuel (Ghosh et al., 2021). In this regard, there are enormous benefits that

result from not using gasoline for transportation and eliminating diesel vehicles because of the pollution they cause (Sher et al., 2021). The continuous increase in pollution rates will lead to the collapse of the environment and difficulty in achieving sustainability (Liao et al., 2021; Wei et al., 2021). Therefore, a strategic shift to EVs should be one way of moving toward a green, resilient, inclusive, and sustainable future. Nowadays, it seems that the concept of sustainable development shapes the bulk of contemporary environmental policies (Vanegas Cantarero, 2020). Its generality plays a role in making it a popular and impressive slogan that almost all governments adopt as a political agenda, as does the EV industry.

Therefore, to increase the penetration of these vehicles, the promotion of EV charging stations is necessary (Pan et al., 2020). Two main factors for the growth, superiority, and spread of any industry using new technologies are the support and incentives provided by the state for that industry and its capability to develop rapidly and overcome its associated defects and obstacles (Thananusak et al., 2021). According to the first, all markets in which EV sales thrive, whether imported or manufactured and assembled locally, must adopt an integrated system to support consumers and manufacturers of these vehicles (Ghosh et al., 2021). On the other hand, the success of such developments, as previously mentioned, depends on the capability of the new industry to avoid the defects and obstacles that hinder its spread and consumer demand (Ghosh et al., 2021). The main disadvantages facing the increase in EVs are their relatively high cost of production and their usual patterns of refuelling. For example, the length of time a battery is charged, it may take a lot of time up to at least 8 h in the case of using a regular electrical outlet in the house. Even the fastest charging stations take at least 30 min to reach nearly 80 percent of their capacity. Therefore, setting up a large number of charging stations in different places that support fast charging is the most suitable solution even though, it may affect a battery's life (Anthopoulos & Kolovou, 2021). Lastly, a good system and infrastructure are important for the production and use of this type of car, its parts, and charging stations to grow.

Sustainability is a philosophy with a new vision of searching for social structures, economic activities, production and consumption patterns, and technologies that work to sustain the environment, empower the current generation, improve lives, and ensure a suitable future (Digalwar et al., 2021). In this regard, the electric car industry relies on the principle of re-formulating current activities and inventing new ones, and then working on integrating them into the existing environment (Cihat Onat et al., 2020). Therefore, sustainable development that is culturally acceptable, economically feasible, environmentally appropriate, politically viable, and socially just is required. However, as achieving EVs and related items, such as charging stations, can mean different, and sometimes contradictory, things to economists, environmentalists, and others, it is troublesome to characterize their prospective significance (Feng et al., 2021). It seems that obtaining a consensus on these points of view is a rather complicated task.

The multiplicity of viewpoints, complexities, and ambiguities involved in evaluating the selection of the most sustainable location for an EV charging station requires the application of classic, fuzzy (Zadeh, 1965), intuitionistic fuzzy (Atanassov, 1994), or neutrosophic theories (Smarandache, 1998) rather than the use of crisp numbers. Choosing the neutrosophic one is because of its capability to deal more accurately with ambiguity in the data and identifying incompatible and indefinite information (Abdel-Basset et al., 2021). It considers the indeterministic, fundamental part of its evaluation, which is represented in all the numbers that express it, such as the triangular, trapezoidal, bipolar, interval, and type-2 neutrosophic numbers (T2NNs). Type-1 neutrosophic numbers are characterized by the formula of a triplet (truth membership (T), indeterminacy (I), and falsity

membership (F)), all of which are in a range of [0, 1]. Also, a T2NN is defined in the form  $\langle (T_T, T_I, T_F), (I_T, I_I, I_F), (F_T, F_I, F_F) \rangle$ , i.e., each neutrosophic element is divided into its T, I, and F sub-parts. T2NNs are applied in our problem because of their capability to accurately express ambiguity, as each part of a number is divided into sub-parts (Abdel-Basset et al., 2019). A T2NN represents a recently developed type of neutrosophic technique. It is an efficient tool for dealing with any imprecision or incompleteness of experts' views. It is also distinguished from other neutrosophic numbers as, in the case of collective decision-making, its type-2 neutrosophic number weighted averaging (T2NNWA) operator is used to collect multiple opinions, which provides it with an advantage in terms of determining the accuracy and relevance of these opinions. Unfortunately, no previous study provided a T2NN-based model for evaluating an EV charging station. Tapia (2021a) suggested using the Data Envelopment Analysis (DEA) method to create a new multi-criteria decision analysis tool for evaluating negative emissions technologies in a neutrosophic setting. Despite Egypt's dependence on transportation based on fossil fuels such as gasoline, it is gradually tending to use EVs as replacements for traditional vehicles (Masiero et al., 2016). Also, there are a few studies related to EVs in Egypt. However, steady steps toward sustainable and comprehensive development in various fields, including the manufacture of EVs, are being taken there. Egypt's government is seeking to achieve sustainability in many areas in compliance with international norms by establishing strict laws and implementing different mechanisms (Nathaniel & Adeleye, 2021). It plans to develop transportation and rely on EVs in various sectors as a step toward reducing pollution and harmful environmental emissions in line with its 2030 Agenda (Gov, 2021). Reliance on EVs necessitates the availability of some basic requirements, such as system support and infrastructure that can help the spread of this new technology (Hutchinson et al., 2018). The most prominent obstacles facing the increase in the use of electric cars are their charging times and the absence of charging stations. Methods for charging electric cars have been developed by specialized companies, with the development process still ongoing (Ramadhani et al., 2020). Also, the existence of charging stations requires the support of governments and the preparation of policies. So, the Egyptian government wants to hire as many companies as possible to set up as many charging stations as possible all over the Republic.

Therefore, choosing the most sustainable location for an EV charging station is a difficult task with many different facets (Wu et al., 2021). It is tainted by some ambiguity as such stations will be established from the ground up without considering the modernization of existing traditional gas ones. Also, the government seeks to achieve the principle of sustainability by considering the main sustainability factors, i.e., economic, social, political, environmental, traffic, and technical. All these factors include many sub-factors that have significant impacts on selecting the most sustainable places to set up EV charging stations. These sub-factors must be considered in the decision-making process. Therefore, making an appropriate choice is a multi-criteria decision-making (MCDM) action. Therefore, a tool for managing decision-making and policy-making seems necessary (Shahnazari et al., 2020). In this study, this problem was dealt with by a hybrid decision-making approach that included two methods known to researchers, interested parties, and specialists, namely, the Decision-making Trial and Evaluation Laboratory (DEMATEL) (Chang et al., 2011) and the Complex Proportional Assessment (COPRAS) ones (Zavadskas et al., 1994). Firstly, the DEMATEL technique was applied to check the inter-relationship between the key factors and sub-factors of the problem. It is an MCDM method that enables their interdependencies to be identified and the proportional relationships among them to be considered (Karaşan et al., 2020). It was also employed to determine their reliance relationships and is a robust method for studying their cause-effect ones based on their similarities. Then, the COPRAS method assumed the direct and relative

reliance of each of the degrees of importance and priority of the substitutes (Ghose et al., 2019). Also, it determined the optimal substitute, taking into account both the perfect and perfect-worst solutions.

To the best of the authors' knowledge, for the first time, the DEMATEL and COPRAS methods are applied in a neutrosophic environment, especially using T2NNs, which are the most accurate types of neutrosophic numbers (Abdel-Basset et al., 2019). Also, for the first time, the T2NNWA operator is used to collect the opinions of specialists regarding the process of evaluating the locations of EV charging stations, which enables more accurate values to be obtained without data loss.

## 1.1 Novelty and contributions

In summary, in this study, a hybrid decision-making approach consisting of the DEMATEL and COPRAS methods in a neutrosophic environment using T2NNs to evaluate six candidate locations for the establishment of EV charging stations in Zagazig, Egypt, is proposed. It involves group decision-making in the evaluation process, which enhances its accuracy. The neutrosophic DEMATEL method is used to obtain the weights of the key sustainability factors in addition to evaluating nineteen sub-factors that have direct impacts on determining the most sustainable locations for charging stations. Subsequently, the neutrosophic COPRAS method is used to rank the alternatives according to their priorities in terms of sustainability. Also, the reason for choosing these two methods is because no other method is better than a MCDM (Amirghodsi et al., 2020). Furthermore, the amalgamation of diverse MCDM techniques can potentially address the limitations of individual methods while leveraging their respective strengths. The integration of multiple evaluation methods can enhance the reliability of decision-making processes, even in cases where a single method may exhibit high levels of uncertainty (Tao et al., 2012). However, each suits a particular problem according to its nature (Amirghodsi et al., 2020).

The contributions of this research are as follows:

- A comprehensive assessment criteria index, including the six main factors: economic, environmental, societal, political, technical, and traffic, as well as nineteen sub-factors, is considered a future basic reference for researchers and academics.
- A new decision-making tool called the "multi-criteria methodology" is proposed that enables people to make reliable decisions even when their input parameters are not very precise.
- The preferences of the decision-makers in the group approach are combined by applying the T2NNWA operator.

The current study has the following structure. A literature review is conducted in Sect. 2. In Sect. 3, the factors and sub-factors for evaluating the locations of EV charging stations are described. The proposed decision-making framework is explained in Sect. 4. Results and discussion are introduced in Sect. 5. Finally, the conclusions are drawn and suggestions for future work are presented in Sect. 6.

## 2 Literature review

Sustainable mobility is critical for the green transition. By utilizing sustainable mobility practices, we can work toward reducing the negative impact of transportation on the environment while ensuring that we can move efficiently and safely. Csutora and Zsóka (2023) suggest that integrating low-mobility societies, collective transport, and electro-mobility represents a promising approach to sustainable mobility, provided their simultaneous application can be demonstrated. In addition, Hirai (2022) notes that new indicators must be developed to evaluate performance, identify appropriate policies, and map out sustainable development pathways. By adopting sustainable mobility practices and measuring our progress through indicators, we can reduce greenhouse gas emissions, enhance social and economic sustainability, and contribute to the green transition. The literature also suggests that the development and implementation of sustainable mobility technologies and practices, such as electric vehicles, can play a crucial role in reducing emissions from the transportation sector, which is responsible for a significant portion of global carbon emissions (D'Adamo et al., 2023). Overall, the sustainable development of mobility is vital for achieving a sustainable and low-carbon economy, and we must prioritize sustainable mobility practices and technologies to achieve the green transition.

In recent years, EVs have been widely adopted as alternatives to conventional vehicles because they reduce greenhouse gas emissions. Also, the electric car industry has attracted the interest of researchers in many fields. Consequently, several studies regarding determining the best location for an EV charging station have been published. Yagmahan and Yılmaz (2023) developed a study for assessing locations for EV charging stations to meet the charge demand under sustainability. Their approach adopted the four MCDM methods, group aggregation techniques (GATs), the Analytical Hierarchical Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA). Ahmad et al. (2022) introduced a study to determine the optimal location of the EV charging station and its impact on the distribution network. Rani and Mishra (2021) suggested a new Multi-objective Optimization based on Ratio Analysis with Full Multiplicative Form (MULTI-MOORA) for determining the best location of an EV charging station under fermatean fuzzy sets. Feng et al. (2021) developed the MCDM technique, comprising the Linguistic Entropy Weight (LEW) and the Fuzzy Axiomatic Design (FAD) methods. The latter took into account five main criteria: technical, economic, social, environmental, and resource, and their thirteen sub-criteria. Mishra et al. (2021) undertook a study to determine the optimal sustainable locations for EV charging stations in India. In their assessment process, they considered the four main dimensions of the environment, economy, society, and technology, and twelve sub-criteria. Their approach adopted the Additive Ratio Assessment (ARAS) method based on a single-valued neutrosophic number. Anthopoulos and Kolovou (2021) introduced a MCDM approach for the deployment and implementation of an EV charging infrastructure in Greece. It adopted AHP method for evaluating five principal criteria and thirteen sub-criteria. Liu et al. (2020) provided a fuzzy MCDM approach for identifying appropriate locations for charging stations. They established an evaluation criteria system consisting of three main criteria and eighteen sub-criteria. Their approach comprised the three MCDM methods: the Entropy Weight Method (EWM), the Best–worst Method (BWM), and the Gray Relation Analysis (GRA). Ghosh et al. (2021) conducted a novel study in which the hexagonal fuzzy MCDM technique for selecting the locations of EV charging stations in India was applied. They adopted the Geographic Information

System (GIS), AHP, TOPSIS, and COPRAS methods for arranging the determined locations. They took into account four key criteria: economic, environmental, traffic, and societal, and thirteen sub-criteria in the assessment process. Ecer (2021) presented a novel approach combining six MCDM methods for ranking ten EV batteries based on eleven criteria to make the right decision regarding the purchase of a battery EV. Their results indicated that the Tesla Model S was the best choice. Karaşan et al. (2020) undertook a study to select the best locations for EV charging stations in Turkey. Their approach consisted of the three MCDM methods: DEMATEL, AHP, and TOPSIS based on intuitionistic fuzzy sets. Çakır et al. (2022) presented a cylindrical neutrosophic single-valued fuzzy MCDM framework for identifying the optimal location of an EV charging station. Baherifard et al. (2022) presented a study about providing intelligent planning to maximize potential charges for EVs in commercial parking lots to raise EV users' profits.

Also, in many papers published about the EV industry, MCDM techniques were adopted as the main methodologies (Tarei et al., 2021). Zhang et al. (2023) developed a paper-based multi-criteria group decision support model for assessing EV charging station location. Loganathan et al. (2021) introduced a study-based MCDM approach for selecting the best battery based on cathode–anode materials, which would help EV manufacturers' decisions using the Weighted Sum Model (WSM) method in the evaluation process. Sonar and Kulkarni (2021) presented a novel hybrid MCDM approach for selecting the best substitute for an EV. It comprised two MCDM techniques: the AHP to evaluate the factors and the Multi-attributive Border Approximation Area Comparison (MABAC) to rank the substitutes. Tarei et al. (2021) conducted a study for identifying the barriers that face the adoption of EVs in India, which relied on the two MCDM methods: BWM and Interpretive Structural Modeling (ISM). Their findings showed that performance and range barrier have critical impacts on EV adoption. Asadi et al. (2022) presented a study that identified the most important challenges facing the spread of EVs in Malaysia, which were analyzed based on the DEMATEL method. Their results indicated that the environmental factor was the most important one.

Also, sustainability has drawn the attention of researchers for their studies in various fields, such as renewable energy (Collotta et al., 2019) and the electric car industry, regarding applying environmental protection laws and providing opportunities for future generations. Hoque et al. (2020) presented a study in which they evaluated alternative fuels rather than fossil fuels and reviewed all studies related to environmental, social, and economic sustainability factors. Yaqoob et al. (2021) introduced a paper for emphasizing the significance of modern technologies and the decreasing of gases emission. Also, they made a comparison of the fuels used for transportation in Pakistan and the future of vehicles was also discussed to analyze the trend of transportation and EVs for a sustainable future. Pamucar et al. (2021) introduced a MCDM approach for evaluating sustainable road transportation in New Jersey, USA. Wei (2021) presented a study that assessed the sustainability of photovoltaic poverty alleviation projects in China. Elkadeem et al. (2021) developed a GIS-based MCDM approach for selecting a sustainable location for a hybrid renewable energy system in Kenya.

Also, several studies related to the neutrosophic theory for dealing with data ambiguity and uncertainty were conducted. Aydın et al. (2020) evaluated solar energy systems in a neutrosophic environment in terms of their capabilities to deal with uncertainty. Tapia (2021b) introduced a model for developing a linear program using the neutrosophic theory and applied it in two cases: a poly generation plant and a combined bio refinery. Simic et al. (2021) proposed a MCDM methodology based on T2NNs for determining a transportation pricing system. Deveci et al. (2021) used a MCDM approach, including a MABAC method



based on T2NNs, to select the best location for a wind farm in the USA. They considered three main criteria and eighteen sub-criteria in the assessment process, as well as five alternatives along the New Jersey coast. Sánchez-Garrido et al. (2021) evaluated the sustainability of structural designs in a neutrosophic environment using triangular numbers.

Finally, some studies were related to DEMATEL and COPRAS methods. Lahane and Kant (2021) proposed a hybrid MCDM approach comprising Pythagorean fuzzy AHP and Pythagorean fuzzy DEMATEL methods to identify barriers for applying Circular Supply Chains (CSC). In it, the AHP was used to determine the barriers' weights and DEMATEL to identify the causal area between the determined CSC barriers. Liang et al. (2021) used the Delphi technique to analyze the factors influencing the economic procedures for EV charging stations and the DEMATEL-ISM method to determine and investigate the factors affecting them. Rao (2021) presented a hybrid MCDM model for enhancing estimations of firm sustainability factors. It consisted of the DEMATEL and the Analytical Network Process (ANP) techniques for investigating the causes and weights of the factors. Dhiman and Deb (2020) proposed a hybrid MCDM approach for identifying a preferable wind farm strategy. It comprised the two MCDM techniques, TOPSIS and COPRAS that were applied to rank the determined alternatives. Ghose et al. (2019) developed a combined fuzzy COPRAS approach, a hybrid MCDM analogy, to investigate six renewable energy systems in India according to eight criteria.

In this paper, a general evaluation system consisting of six key factors and nineteen sub-factors is established to assess the sustainability of EV charging stations. Then, an MCDM approach combining DEMATEL and COPRAS methods is proposed. These methods are used under a neutrosophic environment with T2NNs to evaluate the key factors and their sub-factors and rank the alternatives, respectively.

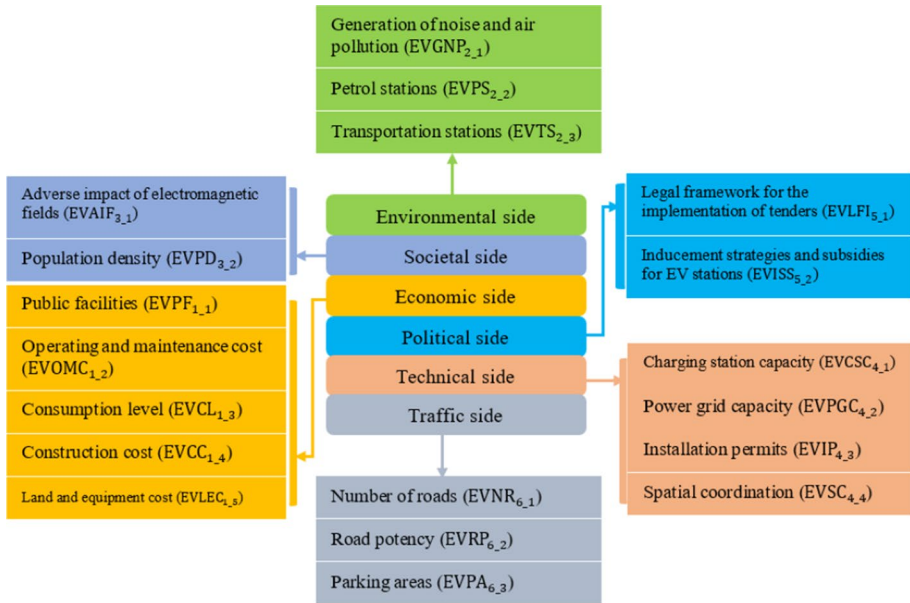
### 3 Factors for evaluations of locations of electric vehicle charging stations

EV charging stations have begun to spread in various countries, especially those with streets dense with this type of vehicle. Consequently, choosing sustainable locations for charging stations has become a significant issue. Previously, researchers focused on some key factors of this problem, such as economic, environmental, and societal ones, which do not include all necessary factors of the evaluation process (Anthopoulos & Kolovou, 2021; Ghosh et al., 2021). But at the present time, there are other factors that must be taken into account, such as technical and political aspects, and traffic. Accordingly, in this paper, a complete index system that could be used when selecting a sustainable location for an EV charging station is created. It is divided into the following six key factors: economic, environmental, societal, technical, political and traffic, each of which includes several sub-factors, as shown in Fig. 1. For clarity, the letters 'EV' are added to all the abbreviations of these key factors and their sub-factors.

#### 3.1 Economic factor (EVECS<sub>1</sub>)

This is one of the main criteria that must be taken into consideration when evaluating the establishment of any development project, such as our problem of determining the best location for setting up an EV charging station. Also, the development process is a holistic one, with multiple goals and fields interconnected with and influenced by each





**Fig. 1** Key factors and their sub-factors that influence the selection of the location of the EV charging station

other (Dang et al., 2021). At the same time, its nature and requirements vary from country to country and from one economic sector to another. A development project is one of its cornerstones as it is not a goal in itself but rather a means of achieving economic goals in a more general and comprehensive manner (Abdel-Basset et al., 2021). The economic sub-factors of our problem are public facilities, operating and maintenance costs, consumption level, construction costs, and land and equipment costs.

- Public facilities (EVPF<sub>1\_1</sub>)

This sub-factor refers to how close the location of an EV charging station is to public facilities, such as schools, universities, and shopping centers, which people use daily. Also, setting up a charging station in any region will fundamentally change its economy because the development process is an intertwined one with many forms (Ghosh et al., 2021).

- Operating and maintenance costs (EVOMC<sub>1\_2</sub>)

This sub-factor refers to the procedures and continuous chain of operations that must be undertaken to place a project in a ready state and good working order. It aims to achieve stable operating conditions and, therefore, provide a good working environment as well as ensure safe conditions and climates for work locations. Also, it reduces the number of malfunctions and the economic loss they cause to a facility as well as the cost of re-operation, that is, a good planning of charging stations reduces costs in general. Although a project for establishing EV charging stations may require high initial operating costs, the long-term benefits outweigh them (Anthopoulos & Kolovou, 2021).

- Consumption level (EVCL<sub>1\_3</sub>)

This sub-factor indicates the extent to which increases in consumption affect people's search for new alternatives, such as EVs, their accessories, and electric charging stations. Therefore, charging stations can be built in areas with high consumption levels or, in other words, highly affluent ones, where they will meet the needs of people who travel more than others (Ghosh et al., 2021).

- Construction cost (EVCC<sub>1\_4</sub>)

Before proceeding with the construction process, its prices must be checked by comparing the charging station that will be built with an existing one in terms of their specifications and final forms (Wei, 2021). As costs may vary depending on the location of a charging station, to complete the construction process, the initial ones should be reduced as much as possible (Ghosh et al., 2021). If the location is well-served by multiple modes of transportation, then the cost of transporting construction materials will be reduced, resulting in lower construction costs and an increase in the initial profitability of the charging station (Ghosh et al., 2021).

- Land and equipment costs (EVLEC<sub>1\_5</sub>)

This sub-factor refers to the cost of purchasing the land and equipment for setting up an EV charging station. The cost of buying land differs from one place to another and also between urban and agricultural land (Haddad et al., 2021). Therefore, as the cost of purchasing expensive land must be reduced, if possible, an existing station should be re-used.

### 3.2 Environmental factor (EVENS<sub>2</sub>)

This is one of the main factors for evaluating the location of an EV charging station (Feng et al., 2021). It refers to the set of conditions that must be met or maintained for a particular environmental component and function, including the policies that regulate the impacts of human activity on them. Environmental criteria must be adhered to protect human health and preserve the living environment. This factor includes some sub-factors, such as the generation of noise and air pollution, as well as that of petrol and transportation stations.

- Generation of noise and air pollution (EVGNP<sub>2\_1</sub>)

This sub-factor refers to some forms of pollution, such as those sounds and air, which are considered the most difficult types in terms of their impacts on the environment (Ullah et al., 2021). The further development of transportation, communications, and charging stations will lead to the purification of carbon in the air and a reduction in heat emissions. Also, reducing noise is important when deciding to put an EV charging station so that it does not disturb people who live nearby (Anthopoulos & Kolovou, 2021).

- Petrol stations (EVPS<sub>2\_2</sub>)

This sub-factor indicates the effects of there being many petrol stations in an area, which will result in the presence of large numbers of vehicles. Setting up an EV charging station next to them will increase these numbers and economic returns while reducing costs.

- Transportation stations (EVTS<sub>2\_3</sub>)

This sub-factor indicates the extent to which transportation stations in general, such as car and railway ones, affect the environment. Replacing them with EV charging ones will lead to the spread of EVs and result in the preservation and/or improvement of environmental factors. Also, although the transition stage from traditional to electric transportation based on clean fuels will take a long time, benefits will eventually be achieved.

### 3.3 Societal factor (EVSOS<sub>3</sub>)

This factor refers to the social and ethical dimensions being alongside the economic ones and the responsibility to consider their important problems to improve society as a whole after its decline due to technology (Mostafaeipour et al., 2021). This will be achieved through a permanent commitment to the requirements of community development and improvements in the awareness, level, and conditions of life of its members (Ullah et al., 2021). The commitment of the business sector includes focusing on laws and ethical criteria. Also, social responsibility should be understood as an investment in society rather than an act of charity, as it goes beyond voluntary philanthropy to create a relationship that benefits both the giver and the recipient. It involves two important sub-factors: the adverse impact of electromagnetic fields and population density (Ghosh et al., 2021).

- The adverse impact of electromagnetic fields (EVAIF<sub>3\_1</sub>)

This sub-factor indicates the extent of the precautions and measures that must be taken into account when constructing EV charging stations because of the magnetic fields they generate that may cause harm to neighboring populations (Ghosh et al., 2021). It is important because public health is the responsibility of every society.

- Population density (EVPD<sub>3\_2</sub>)

This sub-factor indicates how important it is to establish an EV charging station wherever there is a high population density. As it may reduce the quality of life, it is necessary to include it in the evaluation process.

### 3.4 Technical factor (EVTE<sub>4</sub>)

This factor refers to the commitment to implement the technical standards and requirements issued by competent authorities (Kaya et al., 2020), such as the Electricity and Production Regulatory Authority, as well as the country's standard specifications for the

works, equipment, and materials. Also, approval of all design work and supervision of the implementation of EV charging equipment will be conducted by qualified consulting offices. This factor consists of the capacities of the charging station and power grid, installation permits, and spatial coordination.

- The capacity of the charging station (EVCSC<sub>4.1</sub>)

This sub-factor indicates the number of charges a charging station can provide to EVs daily. Also, when setting up a charging station, the number of shipments it provides must be considered, as the higher the number, the greater the return. In addition, the station must be designed for a rate of shipments commensurate with the rate of vehicles in the region so that it is not established with a large number of shipments, the estimated number which is not implemented daily. Some stations can provide approximately 60 charges per day and others 26, depending on the energy entering the station, that is, 50 or 22 kW, respectively (Schroeder & Traber, 2012).

- The capacity of the power grid (EVPGC<sub>4.2</sub>)

This sub-factor refers to the efficiency of the relevant power network to accommodate the construction of a new charging station in the specified location (Anthopoulos & Kolovou, 2021). It may be necessary to replace and renew transmission networks and rehabilitate old power plants in a way that contributes to reducing electrical losses and increasing the efficiency of electrical energy or installing new transformers (Burnham et al., 2017). All these aspects should be taken into account when evaluating this sub-factor for setting up a charging station.

- Installation permits (EVIP<sub>4.3</sub>)

This sub-factor refers to the licenses required for the process of setting up an EV charging station, which are important when choosing its location. Also, policies that encourage people and the private business sector to invest in EVs and their related accessories should be developed because of their long-term benefits.

- Spatial coordination (EVSC<sub>4.4</sub>)

This sub-factor refers to committing to spatial coordination in accordance with the specifications set by the municipalities of the relevant country (Bakker et al., 2014). Also, adhering to several conditions inside a station, such as locating its charging equipment where an EV's wheels will be and placing distinctive signs indicating EV parking spaces and other requirements in each location, is necessary.

### 3.5 Political factor (EVTES<sub>5</sub>)

This factor indicates the extent to which governments are interested in developing policies that encourage a transition to use renewable and clean energies (Kul et al., 2020). Also, the government has a role in providing facilities for transitioning to modern means

of transportation that rely on electricity as an energy source and promoting investment in markets developing charging infrastructure. This factor involves two sub-factors, a legal framework for the implementation of tenders as well as inducement strategies and subsidies for EV charging stations.

- Legal framework for implementation of tenders (EVLFI<sub>5\_1</sub>)

This sub-factor indicates the extent to which some policies stimulate the rapid development of markets for charging point infrastructure. It also means making markets that are appealing to investors without having to change the law or the way things are done, while still following the rules for tenders that are usually used in different sectors and countries.

- Inducement strategies and subsidies for EV stations (EVISS<sub>5\_2</sub>)

This sub-factor refers to the extent of government financial support for the EV market as well as tax exemptions and fees for a charging station's infrastructure (Fang et al., 2020). Transitioning to the stage of adopting EVs requires sufficient time for people to understand their long-term benefits (Fang et al., 2020).

### 3.6 Traffic factor (EVTS<sub>6</sub>)

This factor refers to some aspects that can help the successful establishment of EV charging stations, with its sub-factors the number of roads, road potency, and parking areas.

- Number of roads (EVNR<sub>6\_1</sub>)

This sub-factor demonstrates the importance of building EV charging stations near road junctions. It will help drivers and car owners by offering them more than one road leading to a charging station which will mitigate congestion (Yao et al., 2019).

- Road potency (EVRP<sub>6\_2</sub>)

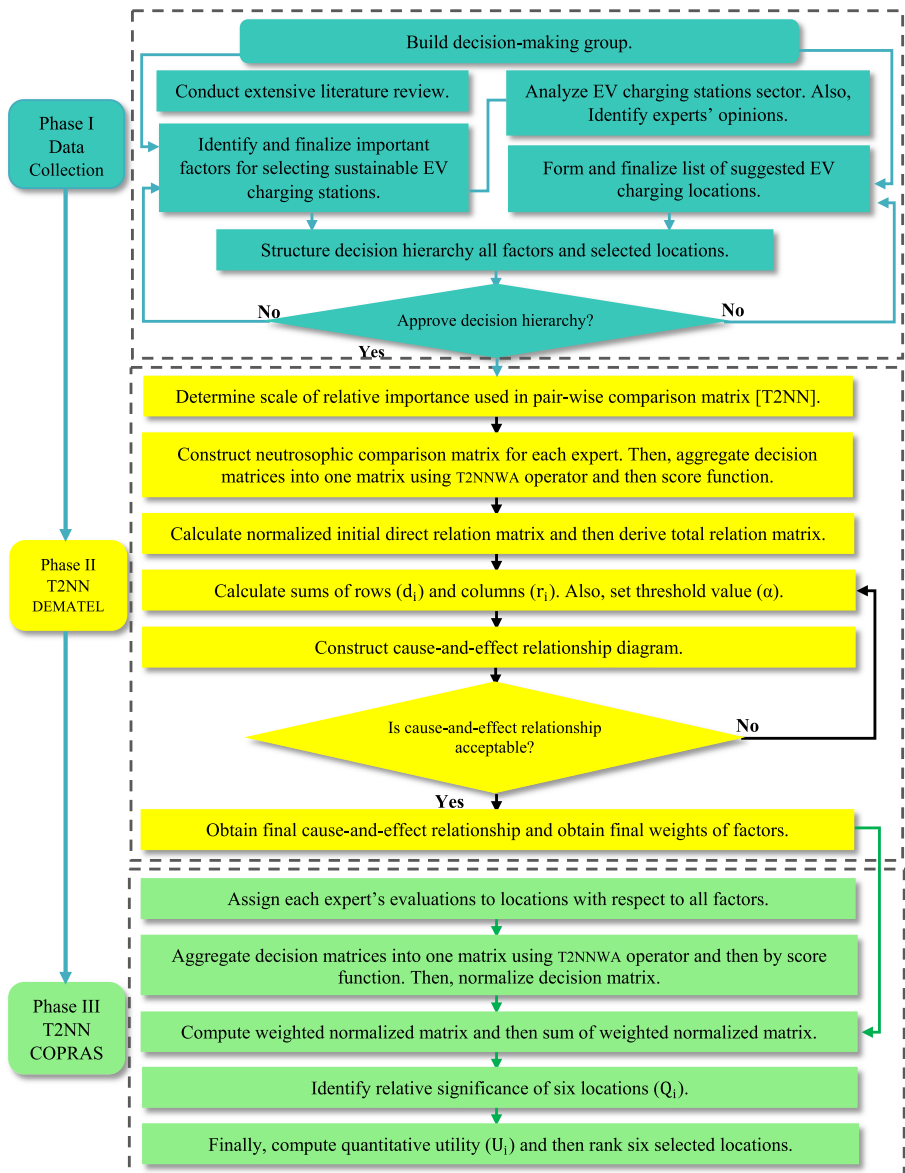
This sub-factor indicates the levels of efficiency of the roads leading to a charging station. The more efficient, the greater the number of passing vehicles and more daily shipments which will increase financial returns and the success of the station (Hosseini & Sarder, 2019).

- Parking areas (EVPA<sub>6\_3</sub>)

This sub-factor refers to how close EV charging stations are to parking spaces where drivers and owners of EVs can charge their cars. It is important in the process of evaluating the most sustainable locations for such stations.

## 4 Materials and methods

In this section, a three-stage conceptual framework for defining a sustainable location for an EV charging station is established by applying DEMATEL and COPRAS methods. Its three stages are: collecting data; determining the weights of the key factors and their



**Fig. 2** The suggested conceptual framework for selecting a sustainable location for the EV charging station

sub-factors which were mentioned in Sect. 3 in detail; and ranking locations in terms of their importance. This framework under a neutrosophic environment using T2NNs is presented in Fig. 2. Its steps are as follows.

*Step 1* Initially, a group of experts who will collaborate with the authors throughout the research period is identified. Also, the weight of each one is determined according to his/her experience, with the sum of their weights equal to 1. Some restrictions regarding their selection are considered. Firstly, they should have sufficient experience, whether academically or in a field of business related to EVs. Their experience should not be less than 15 years, and their academic degrees should be at least Ph.D. Specialists in the field of EVs and some in the field of decision-making related to some of the activities in administration are identified. They are contacted many times, either online or through direct interviews.

*Step 2* The main problem is studied in all its aspects to determine the most important basic steps required to ascertain the key factors and their sub-factors that affect the selection of the most sustainable location for an EV charging station. In general, this is conducted by examining previous relevant literature and analyzing the sector involving EV charging stations, as well as seeking the opinions of experts and researchers.

*Step 3* For this problem, several locations are suggested as alternatives to determine the most sustainable ones for EV charging stations. They are approved by the specialists, and a final list of the proposed ones is prepared.

*Step 4* A final hierarchical structure of the problem is adopted by the study participants to determine its main objective, that is, the selection of a sustainable location for an EV charging station. The key factors and their sub-factors, as well as the final locations used in the evaluation process, are presented.

*Step 5* Linguistic variables and their equivalent T2NNs are identified and used in the process of evaluating the key factors and their sub-factors to make it easier for participants to deal with neutrosophic numbers (Table 2.1, Supplementary Materials). Also, linguistic variables are used to rank the selected locations based on how sustainable they are (Table 2.2, Supplementary Materials).

*Step 6* A decision matrix (G) is built to assess the impact of each factor and sub-factor on the others by the four participants using linguistic variables first (Eq. (1)) and then neutrosophic-scale T2NNs (Eq. (2)).

$$G = \begin{matrix} & K_1 & K_2 & \dots & K_m \\ \begin{matrix} K_1 \\ K_2 \\ \vdots \\ K_m \end{matrix} & \begin{bmatrix} - & KS_{12} & \dots & KS_{1r} \\ \dots & - & \dots & KS_{2r} \\ KS_{31} & \dots & - & \dots \\ KS_{t1} & KS_{t2} & \dots & - \end{bmatrix} \end{matrix} \quad (1)$$

where  $[KS_{rt}]$ ,  $r, t = 1, 2, \dots, m$  and  $KS_{rt}$  is the estimation of the side of the  $r^{th}$  factor  $K_1, K_2, \dots, K_r$  regarding the  $t^{th}$  factor  $K_1, K_2, \dots, K_t$ . Also, as the main diagonal side of the matrix  $= 0.5$ ,  $KS_{rt} = 0.5$ .



$$G = \begin{bmatrix} - & \langle (T_{T_{12}}, T_{I_{12}}, T_{F_{12}}), \rangle & \dots & \langle (T_{T_{1r}}, T_{I_{1r}}, T_{F_{1r}}), \rangle \\ \langle (T_{T_{21}}, T_{I_{21}}, T_{F_{21}}), \rangle & - & \dots & \langle (T_{T_{2r}}, T_{I_{2r}}, T_{F_{2r}}), \rangle \\ \dots & \dots & - & \dots \\ \langle (T_{T_{1l}}, T_{I_{1l}}, T_{F_{1l}}), \rangle & \langle (T_{T_{12}}, T_{I_{12}}, T_{F_{12}}), \rangle & \dots & - \end{bmatrix} \tag{2}$$

where  $\langle (T_T, T_I, T_F), (I_T, I_I, I_F), (F_T, F_I, F_F) \rangle$  is a T2NN in which  $(T_T, T_I, T_F)$  represents the truth split into sub-parts,  $(I_T, I_I, I_F)$  the indeterminacy split into sub-parts and  $(F_T, F_I, F_F)$  the falsity split into sub-parts (Abdel-Basset et al., 2019).

*Step 7* After the decision matrices are built by all the specialists, they are combined into a single matrix by applying the T2NNWA operator (Eq. (3)).

$$\left[ \begin{array}{c} \left( 1 - \prod_{G=1}^n (1 - T_{T_G})^{w_G}, 1 - \prod_{G=1}^n (1 - T_{I_G})^{w_G}, 1 - \prod_{G=1}^n (1 - T_{F_G})^{w_G} \right) \\ \left( \prod_{G=1}^n (I_{T_G})^{w_G}, \prod_{G=1}^n (I_{I_G})^{w_G}, \prod_{G=1}^n (I_{F_G})^{w_G} \right) \\ \left( \prod_{G=1}^n (F_{T_G})^{w_G}, \prod_{G=1}^n (F_{I_G})^{w_G}, \prod_{G=1}^n (F_{F_G})^{w_G} \right) \end{array} \right] \tag{3}$$

where  $U_G = \langle (T_{T_G}, T_{I_G}, T_{F_G}), (I_{T_G}, I_{I_G}, I_{F_G}), (F_{T_G}, F_{I_G}, F_{F_G}) \rangle (G = 1, 2, \dots, n)$  is a group of T2NNS in the set of numbers and  $w_G \in [0, 1]$  the weight vector of  $U_G (G = 1, 2, \dots, n)$  such that  $\sum_{G=1}^n w_G = 1$ .

*Step 8* The T2NNs is used to de-neutrosophied the combined decision to create the initial direct relation matrix (G). This process is computed by applying the score function in Eq. (4).

$$S(U) = \frac{1}{12} \langle 8 + (T_T + 2(T_I) + T_F) - (I_T + 2(I_I) + I_F) - (F_T + 2(F_I) + F_F) \rangle \tag{4}$$

*Step 9* A generalized direct relation matrix (P) is constructed by applying Eqs. (5) and (6).

$$F = \frac{1}{\text{Max}_{1 \leq r \leq n} \sum_{t=1}^n KS_{rt}} \tag{5}$$

$$P = F \times G \quad (6)$$

where  $G$  is the initial direct relation matrix and  $F$  is a set of factors distinguished by a pairwise comparison to express the significance of each factor.

*Step 10* A total relation matrix ( $Q$ ) is constructed by applying Eq. (7).

$$Q = [q_{rt}]_{n \times n} = P \times (Id - P)^{-1} \quad (7)$$

where  $Id$  is a  $(n \times n)$  identity matrix and factor  $q_{rt}$  signifies the indirect effects of factors  $r$  on  $t$ .

*Step 11.* The sums of the numbers in the rows ( $d_i$ ) and columns ( $r_i$ ) in the total relation matrix ( $Q$ ) are calculated by Eqs. (8) and (9), respectively.

$$d_i = \left[ \sum_{t=1}^n p_{rt} \right]_{1 \times n} \quad (8)$$

$$r_i = \left[ \sum_{t=1}^n p_{rt} \right]_{n \times 1} \quad (9)$$

*Step 12* The threshold value ( $\alpha$ ) is set by adding the average of all the numbers in the total relation matrix ( $Q$ ) divided by the number of elements presented in the matrix as exhibited in Eq. (10).

$$\alpha = \frac{\sum_{t=1}^n \sum_{r=1}^n p_{rt}}{n^2} \quad (10)$$

where  $n^2$  denotes the total number of elements in  $Q$ .

*Step 13* A cause-and-effect diagram is constructed. The horizontal vector of  $d+r$  designates the impact of each element in the system, with its highest value denoting the most significant interactions of that element with others (Chen et al., 2021). The vertical vector of  $d-r$  indicates the impact of an element (Shieh et al., 2010). In general, a positive  $d-r$  shows that the element is a cause and a negative one that it is an effect (Shieh et al., 2010). A directed graph is made to show how the chosen key factors and their sub-factors relate to each other. The values in the total relation matrix ( $Q$ ) which meet or surpass  $\alpha$  are measured to be represented into the cause-and-effect diagram.

*Step 14* The final weights of the key factors and their sub-factors are calculated by the  $d$  and  $r$  derived from the specialists' opinions. Then, the final value of  $d+r$  is divided by the sum of its values as

$$w = \frac{d+r}{\sum_{r=1}^n d+r} \quad (11)$$

*Step 15* The weights of the sub-factors are calculated similarly, as in Steps 6 to 14.

*Step 16* The benefit and cost factors are identified. Based on the determined weights, a decision matrix is created between the sub-factors and selected locations by each specialist to determine a sustainable location for an EV charging station using linguistic variables (Eq. (12)) and then neutrosophic scales (Eq. (13)).

$$Y = [y_{rt}]_{i \times j} = \begin{matrix} & E_1 & E_2 & \dots & E_j \\ \begin{matrix} V_1 \\ V_2 \\ \vdots \\ V_i \end{matrix} & \begin{bmatrix} - & y_{12} & \dots & y_{1r} \\ \dots & - & \dots & y_{2r} \\ y_{31} & \dots & - & \dots \\ \dots & y_{t1} & y_{t2} & \dots & - \end{bmatrix} \end{matrix} \tag{12}$$

where  $i$  is the number of selected locations and  $j$  a number of factors.  $y_{rt}$  is the performance evaluation of the  $r^{th}$  substitutes  $V_1, V_2, \dots, V_i$  regarding the  $t^{th}$  factors  $E_1, E_2, \dots, E_j$ .

$$Y = \begin{bmatrix} - & \left\langle \begin{matrix} (T_{T_{12}}, T_{I_{12}}, T_{F_{12}}), \\ (I_{T_{12}}, I_{I_{12}}, I_{F_{12}}), \\ (F_{T_{12}}, F_{I_{12}}, F_{F_{12}}) \end{matrix} \right\rangle & \dots & \left\langle \begin{matrix} (T_{T_{1r}}, T_{I_{1r}}, T_{F_{1r}}), \\ (I_{T_{1r}}, I_{I_{1r}}, I_{F_{1r}}), \\ (F_{T_{1r}}, F_{I_{1r}}, F_{F_{1r}}) \end{matrix} \right\rangle \\ \left\langle \begin{matrix} (T_{T_{21}}, T_{I_{21}}, T_{F_{21}}), \\ (I_{T_{21}}, I_{I_{21}}, I_{F_{21}}), \\ (F_{T_{21}}, F_{I_{21}}, F_{F_{21}}) \end{matrix} \right\rangle & - & \dots & \left\langle \begin{matrix} (T_{T_{2r}}, T_{I_{2r}}, T_{F_{2r}}), \\ (I_{T_{2r}}, I_{I_{2r}}, I_{F_{2r}}), \\ (F_{T_{2r}}, F_{I_{2r}}, F_{F_{2r}}) \end{matrix} \right\rangle \\ \dots & \dots & - & \dots \\ \left\langle \begin{matrix} (T_{T_{i1}}, T_{I_{i1}}, T_{F_{i1}}), \\ (I_{T_{i1}}, I_{I_{i1}}, I_{F_{i1}}), \\ (F_{T_{i1}}, F_{I_{i1}}, F_{F_{i1}}) \end{matrix} \right\rangle & \left\langle \begin{matrix} (T_{T_{i2}}, T_{I_{i2}}, T_{F_{i2}}), \\ (I_{T_{i2}}, I_{I_{i2}}, I_{F_{i2}}), \\ (F_{T_{i2}}, F_{I_{i2}}, F_{F_{i2}}) \end{matrix} \right\rangle & \dots & - \end{bmatrix} \tag{13}$$

*Step 17* After the decision matrices of the key factors and sub-factors and selected locations are built by all the specialists, they are combined into a single matrix by applying the T2NNWA operator according to the weights assigned by each specialist (Eq. (3)).

*Step 18* The combined decision matrix is de-neutrosophied by the T2NNs into real values by applying the score function in Eq. (4) to develop an initial evaluation matrix of the key factors and sub-factors and selected locations.

*Step 19* The normalized decision matrix is determined by

$$L = [l_{rt}]_{i \times j} = \frac{y_{rt}}{\sum_{r=1}^j y_{rt}} \tag{14}$$

*Step 20.* The weighted matrix ( $H=[h_{tr}]_{ij}$ ) is calculated by multiplying the normalized matrix (L) by the weights of the factors ( $W_r$ ) as

$$H = [h_{tr}]_{ij} = l_{rt} \times W_r \tag{15}$$

where  $t = 1, 2, \dots, i$  and  $r = 1, 2, \dots, j$ .

*Step 21.* The sum of the weighted normalized decision matrix is computed as are the sums of the beneficial and non-beneficial factors (Eqs. (16) and (17), respectively).

$$S_{+r} = \sum_{t=1}^n h_{+rt} \quad (16)$$

$$S_{-r} = \sum_{t=1}^n h_{-rt} \quad (17)$$

*Step 22.* The proportional significance of each of the selected locations is calculated by

$$Q_r = S_{+r} + \frac{S_{-min} \sum_{t=1}^j S_{-r}}{S_{-r} \sum_{t=1}^j (S_{-min}/S_{-r})} \quad (18)$$

where  $S_{-min} = S_{-r}$  and  $r = 1, 2, \dots, j$ .

*Step 23.* The quantitative utility is calculated by

$$U_r = \left[ \frac{Q_r}{Q_{max}} \right] \times 100\% \quad (19)$$

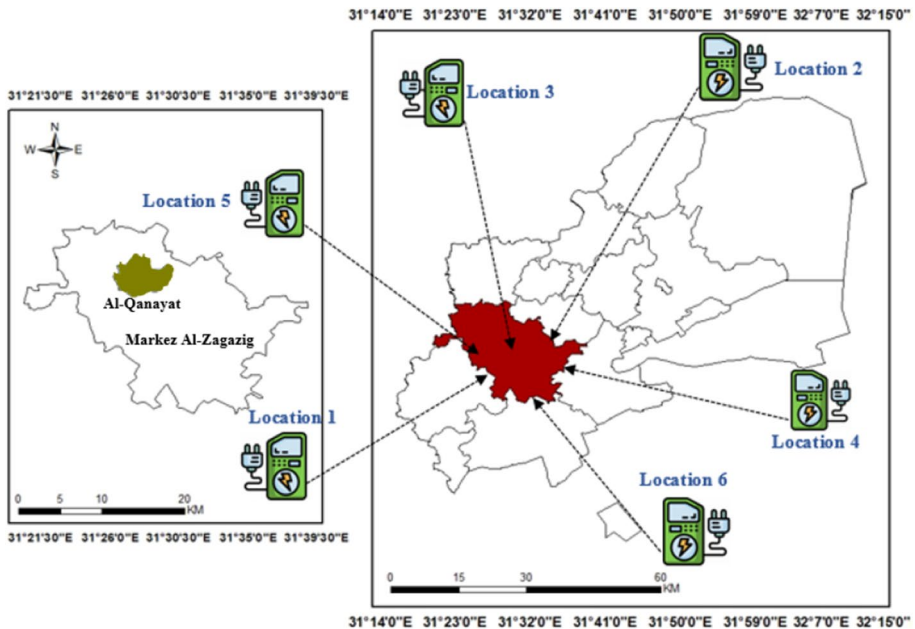
*Step 24.* Finally, the selected locations are arranged according to the most possible value of the quantitative utility.

## 5 Results and discussion

In this section, the steps for implementing the proposed hybrid framework consisting of the DEMATEL and COPRARS methods in a neutrosophic environment using T2NNs according to Sect. 4 are presented. This framework is used to rank the locations of EV charging stations according to their sustainability. Firstly, a case study of the problem is described, with how the participants are configured with the authors and the steps for data collection explained. Secondly, the DEMATEL method is used to calculate the weights of the key factors and their subfactors. Finally, the steps for ranking the candidate locations by the COPRAS method are provided.

### 5.1 A case study in Zagazig

The Egyptian state has been striving for years to enter the world of clean energy and exploit all its resources by switching to working with natural gas and electricity (IRENA, 2018). From this standpoint, the government started working on a new strategy for encouraging the use of EVs in 2019. Its plan includes policies and controls for facilitating investment in EV charging stations, in addition to providing incentives for locally manufactured vehicles. Accordingly, the government intends to establish 1,000 fast-charging stations across the country within the next three years, with the opportunity for the private sector to participate in building more stations. The Egyptian state also announced a tariff for selling electricity during the first year of issuing licenses and determined the official tariff for charging electric cars, which are the two most important obstacles to the spread of this category throughout the Republic. Stakeholders in Zagazig city, Sharkiah Governorate, Egypt, are



**Fig. 3** Geographical locations of six alternative EV charging stations

seeking to identify the best and most appropriate places to establish sustainable EV charging stations. The city's Planning Authority indicated that these required criteria were determined by experts and specialists. Based on them, it decided on several preliminary places for investigation.

The primary places approved by the commission are at the entrances to Zagazig from the following directions: toward Minya al-Qamh (location<sub>1</sub>); Hariyat Razanah (location<sub>2</sub>); Qanayat (Location<sub>3</sub>); Abu Hammad (location<sub>4</sub>); Mit Ghamr (location<sub>5</sub>); and Belbeis (location<sub>6</sub>). The geographical locations of these six alternative sites are presented in Fig. 3.

## 5.2 Steps to implement the proposed framework

*Step 1.* Four specialists in areas of the EV industry are identified to partner with the authors during this study, with decision-making provided by academics and others. Also, a weight (0.35, 0.20, 0.25 and 0.20) is determined for each specialist according to his/her experience.

*Step 2.* The key factors and their sub-factors for use in the evaluation and selection of a site for the construction of a sustainable EV charging station are identified. The main factors are economic (EVECS<sub>1</sub>), environmental (EVENS<sub>2</sub>), societal (EVSOS<sub>3</sub>), technical (EVTES<sub>4</sub>), political (EVTES<sub>5</sub>) and traffic (EVTES<sub>6</sub>). Their sub-factors are public facilities (EVPF<sub>1,1</sub>), operating and maintenance costs (EVOMC<sub>1,2</sub>), consumption level (EVCL<sub>1,3</sub>), construction cost (EVCC<sub>1,4</sub>), land and equipment costs (EVLEC<sub>1,5</sub>), generation of noise and air pollution (EVGNP<sub>2,1</sub>), petrol stations (EVPS<sub>2,2</sub>), transportation stations (EVTES<sub>2,3</sub>), adverse impact of electromagnetic fields (EVAIF<sub>3,1</sub>), population density (EVPD<sub>3,2</sub>), capacity of charging station (EVCSC<sub>4,1</sub>), capacity of power

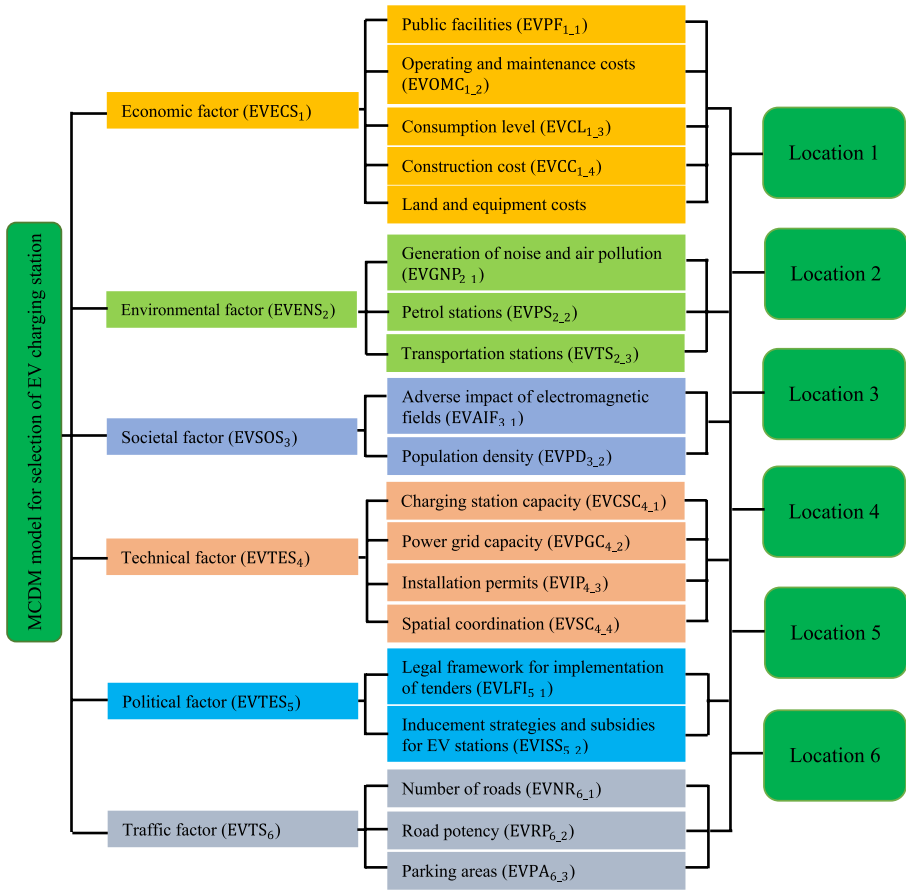


Fig. 4 Hierarchical structure of problem of selecting locations for EV charging stations

grid (EVPGC<sub>4,2</sub>), installation permits (EVIP<sub>4,3</sub>), spatial coordination (EVSC<sub>4,4</sub>), legal framework for the implementation of tenders (EVLFI<sub>5,1</sub>), inducement strategies and subsidies for EV stations (EVISS<sub>5,2</sub>), number of roads (EVNR<sub>6,1</sub>), road potency (EVRP<sub>6,2</sub>) and parking areas (EVPA<sub>6,3</sub>). In addition, to determine the most sustainable location for the establishment of an EV charging station, the six identified are location<sub>1</sub>, location<sub>2</sub>, location<sub>3</sub>, location<sub>4</sub>, location<sub>5</sub> and location<sub>6</sub>.

*Step 3.* A structural diagram is drawn in the form of levels between the four elements of the problem as shown in Fig. 4. The first includes the objective of the study, which is to select a sustainable location for the establishment of an EV charging station; the second is the key factors used in the evaluation process; the third is the sub-factors of each key factor previously identified; and the fourth is the candidate locations used in the evaluation process to select the most sustainable site.

*Step 4.* Several linguistic variables and their equivalent T2NNs for use in the evaluation process to make it easier for the specialists to express their opinions and points of view accurately are defined. The linguistic variables are divided into two parts: firstly, five for evaluating the key factors and their sub-factors, as shown in Table 2.1,

Supplementary Materials; and, secondly, seven others for ranking the candidate locations in the evaluation process to select the most sustainable one for an EV charging station, with the results presented in Table 2.2, Supplementary Materials.

*Step 5.* The process for evaluating the key factors and their sub-factors is divided into two parts. Firstly, the key factors are evaluated and each one weighed, for which four decision matrices are created, one for each specialist, to assess the impact of each one on another by applying Eq. (1) and using the linguistic variables in Table 2.1, Supplementary Materials, with the results shown in Table 2.3, Supplementary Materials. Also, four more decision matrices are built, one for each specialist, to figure out how each factor affects the others by using Eq. (2) and using the T2NNs in Table 1. The results are presented in Table 2.4 in the Supplementary Materials.

*Step 6.* The experts' four decision matrices are combined into a single decision matrix using the T2NNWA operator in Eq. (3), with the results shown in Table 2.5 in the Supplementary Materials.

*Step 7.* The T2NNs are converted to real numbers using the score function in Eq. (4) to obtain the initial direct relation matrix. Then, the generalized matrix is obtained by applying Eqs. (5), and (6), with the results shown in Table 2.6 in the Supplementary Materials.

*Step 8.* The total relation matrix that signifies the indirect effects is obtained by applying Eq. (7) (Table 2.7, Supplementary Materials).

*Step 9.* The sums of the numbers in the rows and columns are obtained by applying Eq. (8) and Eq. (9), respectively, (Table 1).

*Step 10.* The threshold value ( $\alpha$ ) is calculated by adding the average of all the numbers in the total relation matrix divided by the number of elements in it by applying Eq. (10), (Table 1).

*Step 11.* A cause-and-effect diagram of the relationships of the factors determined by all the consultants is constructed, as shown in Fig. 1.1 in the Supplementary Materials.

*Step 12.* The final weights of the key sub-factors are calculated based on dividing the value of  $d+r$  by the sum of the  $d+r$  values according to Eq. (11), with the results presented in Table 1 and Fig. 1.2 in the Supplementary Materials.

*Step 13.* The weights of the sub-factors are calculated as are those of the key factors in the previous steps, as shown in Tables 2.8 to 2.37, and Figs. 1.3 to 1.6 in the Supplementary Materials, with the final ones of the latter presented in Tables 2, 3, 4, 5, 6 and 7. The cause-and-effect diagrams of the relationships of the key factors determined by all the consultants are shown in Figs. 1.7 to 1.10 in the Supplementary Materials.

*Step 14.* The final weights of the key factors and their sub-factors and global weights of the sub-factors are presented in Table 8 and charted in Fig. 1.11 in the Supplementary Materials.

*Step 15.* Cost and benefit sub-factors are identified for all the key factors. The former are  $EVOMC_{1,2}$ ,  $EVCC_{1,4}$ ,  $EVLEC_{1,5}$ ,  $EVGNP_{2,1}$  and  $EVAIF_{3,1}$ , and the latter are  $EVPF_{1,1}$ ,  $EVCL_{1,3}$ ,  $EVPS_{2,2}$ ,  $EVTS_{2,3}$ ,  $EVPD_{3,2}$ ,  $EVCSC_{4,1}$ ,  $EVPGC_{4,2}$ ,  $EVIP_{4,3}$ ,  $EVSC_{4,4}$ ,  $EVLFI_{5,1}$ ,  $EVISS_{5,2}$ ,  $EVNR_{6,1}$ ,  $EVRP_{6,2}$  and  $EVPA_{6,3}$ .

*Step 16.* Four decision matrices are created, one for each specialist, of the sub-factors of the key factors and six locations identified in the evaluation process (Eq. (12)) using the linguistic terms in Table 2.2 in the Supplementary Materials, as shown in Table 3.1 in the Supplementary Materials, and then by the T2NNs (Eq. (13)).

*Step 17.* These four matrices are combined into one decision matrix using the T2NNWA operator by applying Eq. (3), as shown in Table 3.2 in the Supplementary Materials according to the weights previously determined for each specialist based on his/her experience, that is, 0.35, 0.20, 0.25 and 0.20.



**Table 1** Final weights of key factors obtained by all specialists using the DEMATEL method with the threshold ( $\alpha$ ) 0.54368

Specialist <sub>s</sub>	EVECS <sub>1</sub>	EVENS <sub>2</sub>	EVSOS <sub>3</sub>	EVTES <sub>4</sub>	EVPOS <sub>5</sub>	EVTS <sub>6</sub>	Row sum ( $d_i$ )	Column sum ( $r_i$ )	$d_i+r_i$	$d_i-r_i$	Weights
EVECS <sub>1</sub>	0.646	0.526	0.580	0.786	0.716	0.526	3.781	3.568	7.349	0.213	0.188
EVENS <sub>2</sub>	0.731	0.528	0.558	0.854	0.856	0.607	4.133	2.601	6.734	1.533	0.172
EVSOS <sub>3</sub>	0.601	0.534	0.484	0.773	0.705	0.416	3.514	2.692	6.206	0.822	0.159
EVTES <sub>4</sub>	0.607	0.344	0.389	0.572	0.617	0.343	2.872	4.074	6.946	-1.201	0.177
EVPOS <sub>5</sub>	0.414	0.267	0.278	0.476	0.459	0.323	2.217	3.991	6.208	-1.773	0.159
EVTS <sub>6</sub>	0.568	0.402	0.402	0.612	0.638	0.432	3.055	2.648	5.702	0.407	0.146

**Table 2** Weights of economic sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  0.97484

Specialist <sub>s</sub>	EVPF <sub>1,1</sub>	EVOMC <sub>1,2</sub>	EVCL <sub>1,3</sub>	EVCC <sub>1,4</sub>	EVLEC <sub>1,5</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>j</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weights
EVPF <sub>1,1</sub>	0.852	0.939	1.172	0.885	1.261	5.109	3.997	9.106	1.112	0.187
EVOMC <sub>1,2</sub>	0.956	0.935	1.417	1.170	1.302	5.779	4.025	9.804	1.754	0.201
EVCL <sub>1,3</sub>	0.539	0.536	0.860	0.690	0.857	3.482	5.981	9.463	-2.499	0.194
EVCC <sub>1,4</sub>	0.819	0.855	1.282	0.958	1.230	5.144	4.620	9.765	0.524	0.200
EVLEC <sub>1,5</sub>	0.831	0.760	1.250	0.918	1.098	4.857	5.748	10.605	-0.891	0.218

**Table 3** Weights of environmental sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  1.38229

Specialist <sub>s</sub>	EVGNP <sub>2_1</sub>	EVPS <sub>2_2</sub>	EVTS <sub>2_3</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>i</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weight
EVGNP <sub>2_1</sub>	1.314241	1.724629	1.999443	5.038312	3.331985	8.370297	1.706328	0.336
EVPS <sub>2_2</sub>	1.166415	1.35839	1.802818	4.327623	4.08168	8.409303	0.245943	0.338
EVTS <sub>2_3</sub>	0.851329	0.998661	1.224676	3.074666	5.026937	8.101602	-1.95227	0.326

**Table 4** Weights of societal sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  1.76079

Specialist <sub>s</sub>	EVAIF <sub>3_1</sub>	EVDP <sub>3_2</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>i</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weights
EVAIF <sub>3_1</sub>	1.65736	2.65736	4.3147158	2.728453	7.043169	1.586262	0.5
EVDP <sub>3_2</sub>	1.07110	1.65736	2.7284534	4.314716	7.043169	-1.58626	0.5

**Table 5** Weights of technical sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  3.82178

Specialist <sub>s</sub>	EVCSC <sub>4_1</sub>	EVPGC <sub>4_2</sub>	EVIP <sub>4_3</sub>	EVSC <sub>4_4</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>i</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weights
EVCSC <sub>4_1</sub>	4.247	3.364	4.005	3.919	15.536	17.055	32.591	-1.519	0.266
EVPGC <sub>4_2</sub>	4.216	3.236	3.758	3.662	14.873	13.406	28.279	1.466	0.231
EVIP <sub>4_3</sub>	4.886	3.884	4.332	4.232	17.335	15.586	32.921	1.749	0.269
EVSC <sub>4_4</sub>	3.705	2.922	3.490	3.288	13.405	15.102	28.506	-1.697	0.233

**Table 6** Weights of political sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  2.01613

Specialist <sub>s</sub>	EVLFI <sub>5_1</sub>	EVISS <sub>5_2</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>i</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weights
EVLFI <sub>5_1</sub>	1.917871	2.917871	4.83574	3.22942	8.0652	1.6063	0.5
EVISS <sub>5_2</sub>	1.311549	1.917871	3.22942	4.83574	8.0652	-1.6063	0.5

**Table 7** Weights of traffic sub-factors were obtained by all specialists using the DEMATEL method with  $\alpha$  1.23864

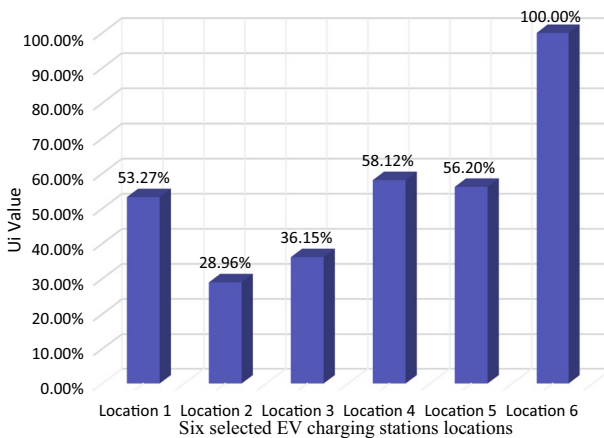
Specialist <sub>s</sub>	EVNR <sub>6_1</sub>	EVRP <sub>6_2</sub>	EVPA <sub>6_3</sub>	Row sum (d <sub>i</sub> )	Column sum (r <sub>i</sub> )	d <sub>i</sub> +r <sub>i</sub>	d <sub>i</sub> -r <sub>i</sub>	Weights
EVNR <sub>6_1</sub>	1.2044	2.0859	1.2807	4.5710	2.9239	7.4950	1.6471	0.336
EVRP <sub>6_2</sub>	0.8327	1.2983	0.7390	2.8700	5.1781	8.0482	-2.3081	0.361
EVPA <sub>6_3</sub>	0.8867	1.7939	1.0255	3.7062	3.0452	6.7514	0.6610	0.303

**Table 8** Global weights of key factors for selecting location of EV charging station

Key factors	EVECS <sub>1</sub> (0.188)					EVEN <sub>2</sub> (0.172)					EVSOS <sub>3</sub> (0.159)				
Sub-factors	EVPF <sub>1,1</sub>	EVOMC <sub>1,2</sub>	EVCL <sub>1,3</sub>	EVCC <sub>1,4</sub>	EVLEC <sub>1,5</sub>	EVGNP <sub>2,1</sub>	EVPS <sub>2,2</sub>	EVTS <sub>2,3</sub>	EVAIF <sub>3,1</sub>	EVPD <sub>3,2</sub>					
Local weights	0.187	0.201	0.194	0.200	0.218	0.336	0.338	0.326	0.500	0.500					
Global weights	0.0352	0.0378	0.0365	0.0376	0.0410	0.0578	0.0581	0.0561	0.0795	0.0795					
Ranks	16	13	15	14	11	3	2	4	1	1					
Key factors	EVTES <sub>4</sub> (0.177)					EVPOS <sub>5</sub> (0.159)					EVT <sub>6</sub> (0.146)				
Sub-factors	EVCSC <sub>4,1</sub>	EVPGC <sub>4,2</sub>	EVIP <sub>4,3</sub>	EVSC <sub>4,4</sub>	EVLFI <sub>5,1</sub>	EVSS <sub>5,2</sub>	EVNR <sub>6,1</sub>	EVRP <sub>6,2</sub>	EVP <sub>6,3</sub>						
Local weights	0.266	0.231	0.269	0.233	0.500	0.500	0.336	0.361	0.303						
Global weights	0.0471	0.0409	0.0476	0.0412	0.0795	0.0795	0.0491	0.0527	0.0442						
Ranks	8	12	7	10	1	1	6	5	9						

**Table 9** Final rankings of six locations selected for EV charging stations were obtained using the COPRAS method

Locations	$S_{+r}$	$S_{-r}$	$S_{-min}/S_{-r}$	$Q_r$	$U_r$ (%)	Rank
Location <sub>1</sub>	0.114988	0.043825	1.000000	0.2008481	53.27	4
Location <sub>2</sub>	0.109201	0.051676	0.848066	0.1092013	28.96	6
Location <sub>3</sub>	0.136300	0.055031	0.796370	0.1363004	36.15	5
Location <sub>4</sub>	0.219121	0.057205	0.766102	0.2191209	58.12	2
Location <sub>5</sub>	0.211871	0.056319	0.778153	0.2118711	56.20	3
Location <sub>6</sub>	0.377020	0.125555	0.349048	0.3770203	100.00	1

**Fig. 5** Final graphical rankings of six locations for EV charging stations obtained using COPRAS method

*Step 18.* The T2NNs are converted to real numbers using the score function in Eq. (4) to develop the initial evaluation matrix for the key factors and the selected locations.

*Step 19.* A normalized decision matrix is calculated using Eq. (14), as shown in Table 3.3 in the Supplementary Materials.

*Step 20.* A weighted normalized matrix is computed by multiplying the normalized one in Table 3.3, Supplementary Materials by the global weight of the key factors in Table 8 using Eq. (15), as shown in Table 3.4, Supplementary Materials. Also, the beneficial and non-beneficial aspects of the factors are determined and shown in Table 3.5, which is part of the Supplementary Materials.

*Step 21.* The sum of the weighted normalized decision matrix is computed and presented in Table 9. Also, the sums of the beneficial and non-beneficial factors are calculated by Eqs. (16) and (17), respectively, as shown in Table 9.

*Step 22.* The proportional significance of each of the six selected locations is computed using Eq. (18) and shown in Table 9.

*Step 23.* The quantitative utility of each of the six selected locations is calculated by Eq. (19) and shown in Table 9. These locations are then ranked according to the most possible value of the quantitative utility, as shown in Table 9 and Fig. 5.

### 5.3 Discussion

In this sub-section, some interpretations of the results obtained are divided into two parts. Firstly, the results for the weights of the key factors and their sub-factors are clarified. Secondly, those for ranking the six candidate locations to establish an EV charging station so that the most sustainable one can be chosen, are explained.

Initially, the weights of the six key factors determined by the four specialists to assess the problem are obtained and evaluated as follows.  $EVECS_1$  has the greatest weight of 0.188, followed by  $EVTES_4$  with a weight of 0.177 and  $EVTS_6$  with the lowest weight of 0.146, as shown in Table 1. Also, based on this table, a cause-and-effect diagram of the key factors of the problem is shown in Fig. 1.1 in the Supplementary Materials, which demonstrates that  $EVECS_1$  has the highest value of the strengths of the impacts given and dispatched by the key factors (7.349 for the sum  $d+r$ ) followed by  $EVTES_4$  and  $EVENS_2$ . In summary,  $EVECS_1$  has the most important impact. On the contrary,  $EVTS_6$  affects the others the least (5.702 for the sum  $d+r$ ). Also, the values of  $d-r$  for  $EVTES_4$  and  $EVPOS_5$  are negative, which indicates that they are affected by others.

Then, the weights of the key factors and sub-factors are obtained according to the assessments of the four specialists. Firstly, the economic sub-factors are determined as follows:  $EVLEC_{1,5}$  has the highest value of 0.218 followed by  $EVOMC_{1,2}$  with a weight of 0.201 and  $EVPF_{1,1}$  has the lowest weight of 0.187, as shown in Table 2 and Fig. 1.3. Also, based on Table 2, a cause-and-effect diagram of the economic ones is charted (Fig. 1.7 in the Supplementary Materials). This figure shows that  $EVLEC_{1,5}$  has the highest value of the strengths of the impacts given and dispatched (10.605 for the sum  $d+r$ ) followed by  $EVOMC_{1,2}$  and  $EVCC_{1,4}$ . In summary,  $EVLEC_{1,5}$  has the most important impact on the economic sub-factors. On the contrary,  $EVPF_{1,1}$  affects the others the least (9.106 for the sum  $d+r$ ). Also, the values of  $d-r$  for  $EVCL_{1,3}$  and  $EVLEC_{1,5}$  are negative which indicates that they are affected by others.

Secondly, the weights of the environmental sub-factors are determined as follows.  $EVPS_{2,2}$  has the highest value of 0.338 followed by  $EVGNP_{2,1}$  with a weight of 0.336 and  $EVTS_{2,3}$  has the lowest weight of 0.326, as shown in Table 3 and Fig. 1.4. Based on Table 3, a cause-and-effect diagram of the environmental sub-factors is charted in Fig. 1.8 in the Supplementary Materials. This figure shows that  $EVPS_{2,2}$  has the highest value in terms of the strengths of the impacts given and dispatched (8.409303 for the sum  $d+r$ ) followed by  $EVGNP_{2,1}$  and  $EVTS_{2,3}$ . In summary,  $EVPS_{2,2}$  has the most significant impact on the environmental sub-factors. Also, the value of  $d-r$  for  $EVTS_{2,3}$  is negative, which indicates that it is affected by others.

Thirdly, the weights of the societal sub-factors are determined as  $EVAIF_{3,1}$  and  $EVPD_{3,2}$  having the same weight value of 0.5 as shown in Table 4.

Fourthly, the weights of the technical sub-factors are determined as follows.  $EVIP_{4,3}$  has the maximum value of 0.269 followed by  $EVCSC_{4,1}$  with a weight of 0.266 and  $EVPGC_{4,2}$  with the minimum weight of 0.231, as shown in Table 5 and Fig. 1.5. Based on Table 5, a cause-and-effect diagram of these sub-factors is presented in Fig. 1.9 in the Supplementary Materials. As it shows that  $EVIP_{4,3}$  has the highest value for the strengths of the impacts given and dispatched (32.921 for the sum  $d+r$ ) followed by  $EVCSC_{4,1}$  and  $EVSC_{4,4}$ .  $EVIP_{4,3}$  has the most important impact. On the contrary,  $EVSC_{4,4}$  affects the others the least (28.506 for the sum  $d+r$ ). Also, the values of  $d-r$  for  $EVCSC_{4,1}$  and  $EVSC_{4,4}$  are negative which, indicates that they are affected by others.

**Table 10** Final rankings of six locations selected for EV charging stations were obtained using different methodologies

Location	MABAC-based T2NNs	TOPSIS-based T2NNs	CRITIC- and MABAC-based T2NNs	Proposed methodology
Location <sub>1</sub>	4	4	3	4
Location <sub>2</sub>	5	6	6	6
Location <sub>3</sub>	6	5	5	5
Location <sub>4</sub>	2	3	2	2
Location <sub>5</sub>	3	2	4	3
Location <sub>6</sub>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>

Fifthly, the weights of the political sub-factors are determined as  $EVLFI_{5_1}$  and  $EVISS_{3_2}$  having the same weight value of 0.5, as shown in Table 6.

Finally, the weights of the traffic sub-factors are determined as follows.  $EVRP_{6_2}$  has the highest value of 0.361 followed by  $EVNR_{6_1}$  with a weight of 0.336 and  $EVPA_{6_3}$  has the smallest weight of 0.303, as shown in Table 7 and Fig. 1.6. Also, based on Table 7, a cause-and-effect diagram of the traffic sub-factors is plotted in Fig. 1.10 in the Supplementary Materials. It shows that  $EVRP_{6_2}$  has the highest value regarding the strengths of the impacts given and dispatched (8.0482 for the total sum  $d+r$ ) followed by  $EVNR_{6_1}$  and  $EVPA_{6_3}$ . In summary,  $EVRP_{6_2}$  has the most important impact. Also, the value of  $d+r$  for  $EVPA_{6_3}$  is negative which indicates that it is affected by others.

According to Table 9, the outcomes obtained by the COPRAS method in the evaluation process demonstrate that location<sub>6</sub> is the most sustainable one of the candidates' ones for an EV charging station followed by location<sub>4</sub>, with location<sub>2</sub> the least suitable.

## 5.4 Comparative and sensitivity analyses

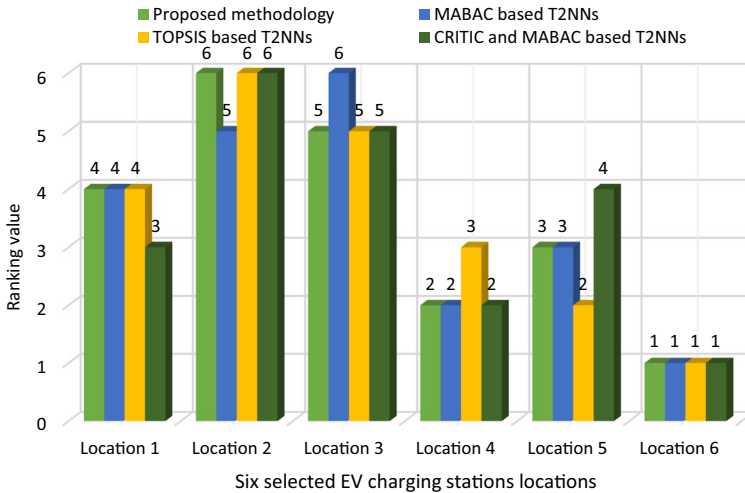
In this sub-section, the results obtained from comparative and sensitivity analyses are presented to show the strength, reliability, stability, performance, and validity of the proposed model.

### 5.4.1 Comparative analysis

In this part, the results obtained from a comparative analysis performed to test and verify the proposed methodology are discussed. The methodology is compared with other T2NN-based ones, those of the MABAC (Deveci et al., 2021), TOPSIS (Abdel-Basset et al., 2019), CRiteria Importance through Intercriteria Correlation (CRITIC), and MABAC ones (Simic et al., 2021). The same weights are used for the main factors and their sub-factors shown in Table 8. The results obtained from the different methodologies for ranking the selected locations are presented in Table 10 and Fig. 6. It can be clearly stated that location<sub>6</sub> is the most sustainable one for setting up an EV charging station and location<sub>2</sub> is the least sustainable one. Considering the MABAC-based T2NNs methodology, location<sub>3</sub> is the last-ranked one.

As is evident in Table 10, although there are some differences in the order of the alternatives using the different methods, they are only slight, and some are due to the methods'





**Fig. 6** Final graphical rankings of six locations for EV charging stations were obtained using different methodologies

different mathematical bases. Finally, a correlation analysis between the proposed and other methods previously mentioned is performed using SPSS software. It is clear that the correlation coefficient between the proposed, MABAC-based T2NNs and TOPSIS-based T2NNs methodologies is 0.943 while that between the proposed and CRITIC and MABAC-based T2NNs methodologies is 0.867. Therefore, it appears that the consistency of the proposed methodology is largely compatible with those of the others, which indicates its reliability.

### 5.4.2 Sensitivity analysis

In this part, the procedures used for sensitivity analysis of the data used to evaluate six locations selected for the construction of a sustainable EV charging station are described. The most important key factors for evaluating the performance of the different alternatives, economic, environmental, social, technical, political, and traffic, are studied. Also, the permanence of one alternative is evaluated by using different weights. Firstly, a sensitivity analysis is performed on each of the key factors separately so that the weight of the selected one is changed from 0 to 1 and the weights of the others are divided equally into the other five factors.

In Fig. 7, the results of the sensitivity analysis for the economic factor are presented. It seems that location<sub>6</sub> is the most suitable site for setting up a charging station until the weight of the factor is 0.6 and then location<sub>1</sub> is the best, starting with a weight of 0.7. On the other hand, location<sub>2</sub> is ranked last despite changes in the weights each time.

In Fig. 8, the changes made to the ranking of locations according to changes in the weight of the environmental factor are presented. Location<sub>6</sub> and location<sub>2</sub> remain the best and worst in the rankings, respectively. Also, as shown, there are some changes in the rankings of other locations, such as location<sub>1</sub>, location<sub>4</sub> and location<sub>5</sub>, at certain weights.

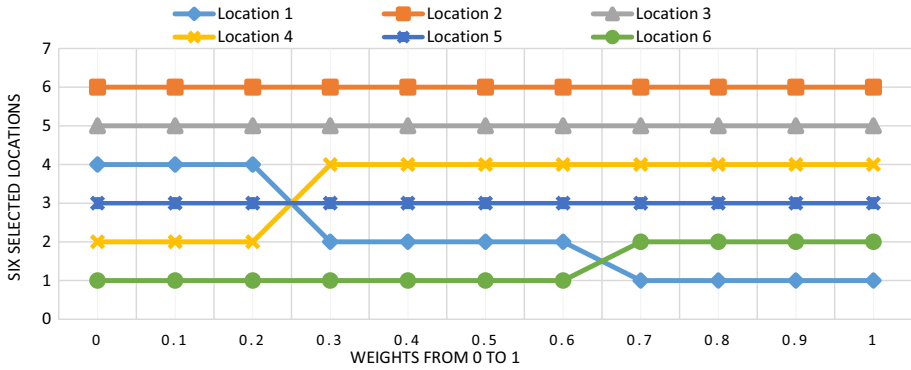


Fig. 7 Rankings of six locations according to changes in weight of economic factor from 0 to 1

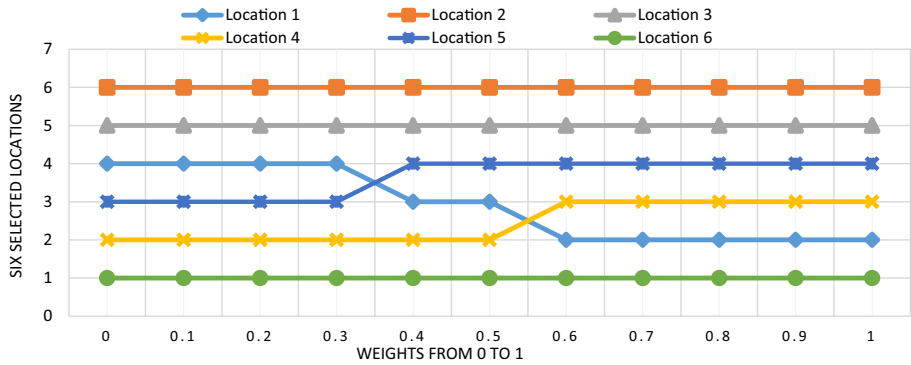


Fig. 8 Rankings of six locations according to changes in weight of environmental factor from 0 to 1

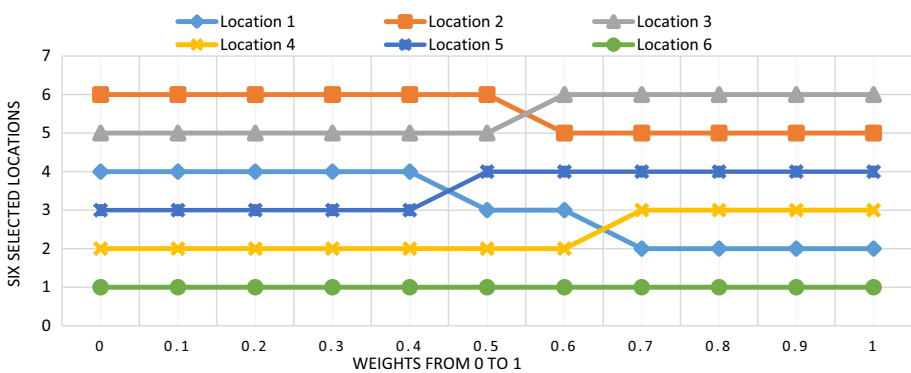
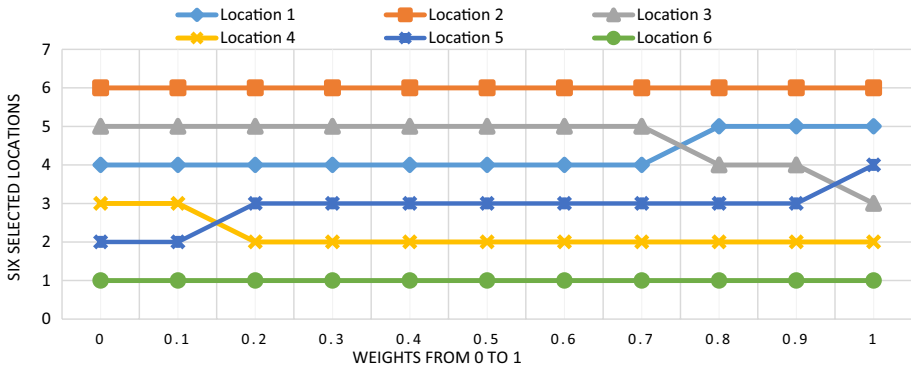
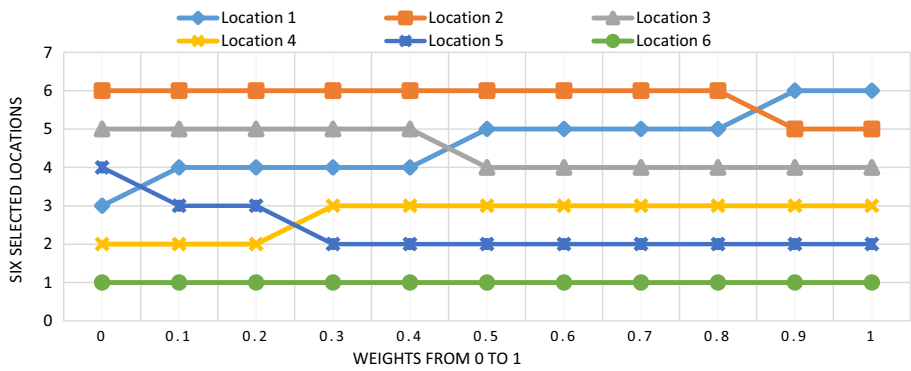


Fig. 9 Rankings of six locations according to changes in weight of societal factor from 0 to 1

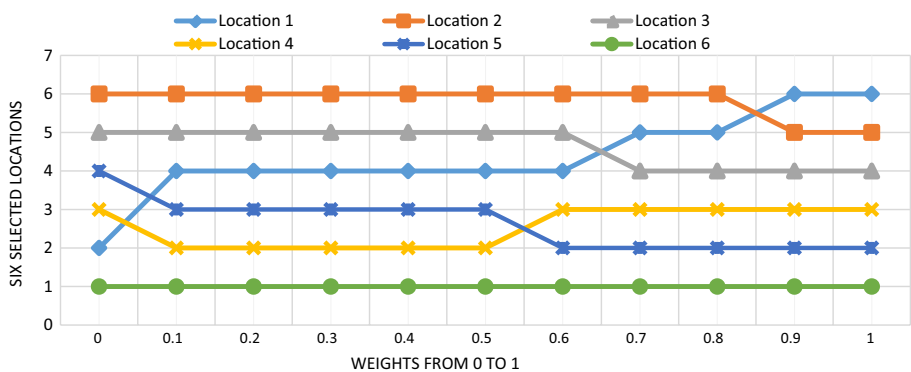
Finally, in Figs. 9, 10, 11 and 12 the changes in the rankings of the selected locations according to changes in the weights for the societal, technical, political, and traffic factors are presented. As for the economic and environmental factors, despite changes



**Fig. 10** Rankings of six locations according to changes in weight of technical factor from 0 to 1



**Fig. 11** Rankings of six locations according to changes in weight of political factor from 0 to 1



**Fig. 12** Rankings of six locations according to changes in weight of traffic factor from 0 to 1

in weights every time, location<sub>6</sub> remains the best for setting up an EV charging station based on the analysis conducted, which means that it is the optimum location in all cases.

## 6 Conclusions and prospects

There is no doubt that many people have started looking at EVs and their economic feasibility recently, especially following rises in fuel prices, the continuous maintenance required for traditional vehicles, and the high cost of petrol and diesel cars. The transition from vehicles powered by fossil fuels, such as gasoline and gas, to EVs will bring benefits to the environment, such as reducing emissions, achieving clear skies, and mitigating harm to human health. Certainly, EVs have many advantages that have helped their increasing adoption, as they are environmentally friendly because they do not emit carbon emissions of any kind, which greatly reduces rates of pollution, especially in crowded cities and given global warming. In addition, they are characterized by their easy maintenance and low cost as most of their maintenance procedures focus on changing their batteries. Also, as the EV industry has imposed itself strongly in the past years and is moving forward in terms of strength and stability through continuous development, with time, the acceptance and widespread adoption of EVs among consumers is increasing. Consequently, various large investment areas will be opened in many fields, such as manufacturing, selling, and/or maintenance, providing spare parts, and perhaps building charging stations for them, which will reap huge profits.

For the growth of any industry with new technologies, the criteria for its superiority and spread are based on two main factors: the support and incentives provided by the state to that industry and its capability to develop rapidly and overcome its associated defects and obstacles. Therefore, in this study, one of the most important problems facing the EV industry, that is, the need for charging stations in suitable places, was considered. The most sustainable location for an EV charging station in Zagazig city, Egypt has been identified. This study was conducted with the participation of four specialists in the field of EVs and decision-making under a neutrosophic environment due to uncertainty about the data related to any new technology.

Six specific locations for EV charging stations (the entrances to Zagazig toward Minya al-Qamh (location<sub>1</sub>), Hariyat Razanah (location<sub>2</sub>), Qanayat (location<sub>3</sub>), Abu Hammad (location<sub>4</sub>), Mit Ghamr (Location<sub>5</sub>) and Belbeis (location<sub>6</sub>)) were evaluated according to six key factors, that is, economic, environmental, societal, political, technical, and traffic, and nineteen sub-factors, that is, public facilities, operating and maintenance costs, consumption level, construction cost, land and equipment costs, generation of noise and air pollution, petrol stations, transportation stations, the adverse impact of electromagnetic fields, population density, capacities of charging station and power grid, installation permits, spatial coordination, the legal framework for the implementation of tenders, inducement strategies and subsidies for EV stations, number of roads, road potency and parking areas.

A MCDM approach consisting of DEMATEL and COPRAS methods was proposed. Firstly, the DEMATEL one was applied to prioritize the key factors and their sub-factors, and then the COPRAS one to rank the six locations determined for the establishment of EV charging stations according to their sustainability. The findings showed that location<sub>6</sub> was the most sustainable, with a weight of 100%, followed by location<sub>4</sub> with a weight of 58.12%.

Although the results verified the proposed approach to be applicable and effective, it had some limitations which could be overcome by: firstly, focusing the suggested T2NN technique on various aggregation operators, such as t-conorm- and t-norm-based Einstein or Dombi operators, to expand its flexibility; and secondly, the criteria for the weights

should be pliable and dynamically altered as the decision-making environment changes. In future work, data will be collected from the public. Also, the number of factors used in the evaluation process, including all those that could affect the selection of locations for EV charging stations, should be increased. In addition, a geographical information system for determining the best locations should be introduced.

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**Data availability** Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest in the research.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

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