smart cities

Article

Expert Evaluation of the Significance of Criteria for Electric Vehicle Deployment: A Case Study of Lithuania

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Abstract: This study presents the hierarchical structure of 50 sub-criteria divided into 7 main criteria for the assessment of electric vehicle (EV) deployment. Two options, Average Rank Transformations and Analytic Hierarchy Process methods, were applied in determining the local weights of the sub-criteria. The sufficient compatibility of expert opinions was accomplished using the averages of the ranks of the main criteria and sub-criteria as the result of solving the problem. The averages of the local weights were calculated employing three Multiple Criteria Decision-Making methods that increased the reliability of the research results. Based on this, the global weights and priorities of the sub-criteria were evaluated. The experts suppose that EV deployment at the national level is mainly affected by the higher cost of manufacturing and purchasing EVs, the application of financial incentives for purchasing EVs, the lack of exhausted gasses, the installation of fast charging points, and the absence of infrastructure in the five largest cities nationwide. The obtained results demonstrate that out of 50 sub-criteria, the cumulative global weight of the 10 most important sub-criteria (mainly based in economics) amounts to more than 35%, whereas that of the 22 most important sub-criteria have a weight above the average (0.2), reaching approximately 65%. The findings can be put into practice by state decision makers of EV deployment.

Keywords: electric vehicle; expert systems; hierarchical systems; road vehicles; sustainable transportation; weight measurement

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1. Introduction

The development of a smart city is not possible without modernising the transport system, particularly through electrification to reduce air and noise pollution. According to the data provided by the European Automobile Manufacturers' Association (ACEA), a long-term decrease in CO_2 emissions was generated by vehicles manufactured in Europe (EU + EFTA + UK), and a 0.3–1.8% increase in the above-mentioned emissions was recorded for the period 2017–2019 [1]. A comparison of the years 2020 and 2021 shows that the rise in Europe amounted to 6.4% (up to 114.7 g/km). As for Lithuania, conforming to the specifications of the newly purchased vehicles, these figures came to an increase of 13.7% or up to 135.7 g/km in CO_2 emissions [2]. In order to reduce the impact of air pollution caused by road transport, the European Parliament and Council reached an agreement ensuring that all new passenger cars and vans registered in Europe would be zero-emission by 2035 [3]. This particular decision made by the government obliged vehicle manufacturers to link their long-term plans with electrification. Due to significant technological changes in vehicle powertrains, this becomes a serious challenge for both users and developers of charging infrastructure.

Electric vehicles (EVs) have gained a tangible increase in the market share only in the last few years; however, the real number of EVs running on the streets is significantly lower. This is due to the natural delay of new products entering the market, especially in middle- and low-income countries, because EVs usually come with higher prices compared with conventional vehicles. Moreover, the transition to electric transport creates significant issues for society with the adoption of a new technology and for the economy with the move from fossil fuels to electricity [4]. It is considered that EV deployment varies per country depending on vehicle cost and energy system configuration; however, objective reasons are often not the same. Though the charging infrastructure has become a common issue when analysing the limitation of EV deployment, financial aspects, policies applied by the state, and approaches toward environmental protection require a separate assessment. An important point is the difference in society purchasing power and companies, which determines a large variation in the average age of the vehicle fleet in different countries. EV deployment depends on a number of different criteria and on the specificities of the country; therefore, it makes sense to conduct expert evaluation to determine the significance of these criteria. Two interrelated contributions are presented in this paper. The first contribution is the development of two options of Average Rank Transformations and Analytic Hierarchy Process methods in order to determine the local weights for the specific research object. The second contribution is based on the application of the developed methods to determine the most sensitive criteria for EV deployment in a geographically and socially bounded environment that will be used by sustainable transport policy makers and implementing authorities.

2. Literature Review

2.1. Electric Vehicle Deployment Issues in Different Regions

Individual countries and regions have both common and specific constraints on EV deployment. China is the largest producer of EVs—in 2023, around 60% of new electric vehicle registrations were in China (with an annual growth forecast of 7%) [5]. Therefore, highlights based on the Chinese market are a valuable example for dealing with the usage of alternative power in the transport sector. Sensitivity analysis using data from Shandong province showed that under a relatively low percentage of EVs, priority had to be given to the quantity and location of public charging points. Then, the higher penetration of EVs into the vehicle fleet requires more attention to be paid to rapid charging points [6]. In addition, demand for non-stationary customer charging and different charging scenarios together with charging station structure is intrinsically linked to the quality of service and EV penetration [6,7]. Another study based on the adoption of electric vehicles in China showed that monetary incentives and administrative controls are more effective in the short term, whereas a lack of purchase restrictions, the development of charging infrastructure, public procurement, and gasoline prices have a long-term impact [8].

The effectiveness of financial subsidies and environmental factors to resolve the deployment of EVs has been examined using the agent-based model [9]. EV adoption decisions, charging activities, and investment in charging infrastructure have been added to the model as an important factor planning financial investment in the future. A data-based simulation from Beijing showed that a reasonable range of subsidy level for EV adopters, construction, and charging points would lead to the smooth deployment of EVs. However, a substantial change in prices (EV sales, gasoline, electricity) or EV driving range may have a different effect on EV deployment; moreover, policy interventions are reasonable measures to control the situation.

The analysis of a case in France was conducted using the mixed-effect regression of socio-demographic, technical, and economic factors in order to determine the market share between battery electric vehicles (BEVs) and Plug-in Hybrid electric vehicles (PHEVs) [10]. Models' availability and energy prices showed a positive correlation of both types of vehicles (commonly named PHEVs). Furthermore, fast charging points are positively related to BEV sales, while slow and middle-power charging points are related to PHEV; however, national subsidies are negatively correlated with PHEV sales. Policy recommendations proposed by the authors of the study are linked to the revision of subsidies, a decrease in electricity prices, subsidies for right charging power at the right place, and the provision of facilities for photovoltaic panel installation.

Significantly increased investment in wind power has been estimated for Northern European countries, which will reduce the need for new coal/natural gas power but only with the implementation of vehicle-to-grid (V2G) [11]. The simulation model based on the data and regulations from the United States (US) market revealed that the implementation of wind capacity incentive policies accelerated the deployment of EVs and charging points [12]. The same study found that higher prices for gas encouraged companies to invest in wind capacity. Analysis of vehicle driving distances in several US states reveals that the deployment of a low-power charging network is sufficient to compensate for the limited range of EVs, as it also requires less investment; however, fast charging points are necessary along interstate corridors [13].

Research on the implication of the EV promotion policy in Thailand has been based on the different types of vehicles predicted by regression analysis according to GDP and the annual population of the country [14]. Three scenarios for different levels of penetration of electric vehicles were analysed for the sustainable operation of the transport and electricity sectors. Renewable energy for electricity generation as a policy-based measure was evaluated in order to achieve a significant reduction in the emissions generated in the transport sector. As a challenging undertaking, the mixture of generating capacity additions, infrastructure expansion, coordinated charging, and time-of-use tariff setting was highlighted, and opportunities related to faster V2G integration were found. However, the authors summarised that the success of the deployment of EVs requires strong government policy support. Another study on the promotion of EVs in Thailand highlighted potential challenges related to uncoordinated home charging [15]. The widespread use of public fast charging is mentioned as one of the solutions to the increase in peak electric energy demand. Another solution from Abu Dhabi is based on an intelligent transportation–energy system that had a coordinated role in energy/distribution management [16].

The demand for smart V2G integration has also been highlighted in the study of mass-scale EV deployment in European countries [17]. Country-specific socio-economic and weather-related factors were found to be significant for both modelling the demand in the power system of the country and consumer preferences. The importance of EV charging reorientation from the uncontrolled fast-charging network to charging during working hours was revealed in the analysed case of Spain [18]. To reduce charging costs and fluctuation in demand for electricity, dynamic charging is found to be an effective measure that mitigates the drawbacks of using electric vehicles [19]. In addition, advanced information services based on mobile applications are an important step towards public acceptance of electromobility [20]. A systematic analysis of the research carried out showed that information about charger point reservation or energy-efficient routing is still relevant and should be better integrated into mobile applications.

An evaluation of the public infrastructure for EV in Lithuania during the initial stage of the deployment of EV showed that the resorts had a relatively higher density of charging points compared to cities of similar size [21]. Multiple Criteria Decision-Making (MCDM) methods used to predict the faster development of charging points indicated that a more coordinated distribution of incentives between municipalities is necessary.

An alternative study was conducted underlying the psychological mechanism for EVs purchase and non-public charger usage [22]. The findings of sustainable alignment between the purchase intention of EVs and the trend of promotion of green products were also generated. Another study based on a hybrid choice model analysed the observed and latent variables for EV purchase [23]. A model has been developed that allows for nonlinear relationships between the utility of choice alternatives and their explanatory variables. A survey conducted clearly showed an intention to purchase EVs for people with a strong preference for modern technologies.

2.2. Expert Evaluation-Based Studies for Sustainable Transport

In order to develop a reliable impact model for EVs on the road network, specific surveys of charging infrastructure and electricity demand are necessary because publicly available national travel surveys are not detailed enough [24]. It is also recommended that common surveys for all countries in the same region be performed to obtain unified data. Presenting group aggregation techniques for the Analytic Hierarchy Process (AHP), it is important that individual preferences and judgments regarding the evaluation of criteria should be anticipated in advance [25]. The small expert group assumes a greater cohesion; therefore, pairwise comparison matrices work better with only limited cases. Moreover, two aggregation procedures can be conducted for data collected from the survey within the AHP method [26]. This depends on whether the group of decision makers is homogenous. Another aspect is when experts who are typically not experts in the AHP methods are experts in a specific field.

A research study based on semi-structured interviews demonstrated that EV cost, charging infrastructure, and public policies were the main barriers to the diffusion of EVs in the Brazilian market [27]. The main solutions also applicable to other countries were defined as an increase in consumer awareness of emissions from fossil fuel vehicles as well as tax and non-tax incentives related to EV purchase and exploitation and technological advances linked to battery performance and reduced charging time. A similar study on the identification and prioritisation of customer and technical requirements to expand the EV market was conducted in India [28]. The Quality Function Deployment method and the AHP approach were used to process interview-based survey data. The limited availability of public charging points was found to be the main barrier, while the maintenance of EVs and charging time were found to be the least important.

An adoption of lightweight AHP was developed to express its versatility of application, such as allowing vehicle parking selection algorithms to shortlist the best parking spots [29]. Only three criteria were used for this purpose (number of free spots, walking time to the final destination, and parking cost); however, the alternatives available for each solution were predetermined.

Another approach employing the AHP based multi-criteria method was used to rank various strategies to mitigate on-road emissions [30]. A process of the survey conducted showed that the reduced strategies had the highest preference score compared to the avoid and replace strategies; however, a mixed scenario for CO_2 mitigation was suggested to implement more comprehensive measures. A three-stage survey was conducted in Yurihonjo (Japan) using AHP for the deployment of EVs to express expert knowledge about transport systems [31]. This study highlights that the public transportation system should meet the requirements of potential passengers.

Multi-criteria analysis methods are also used to predict various sustainable transport solutions, allowing the opportunity to classify and evaluate policy packages from an expert's perspective [32]. Moreover, the combination of content and AHP analyses has been found to be a promising tool in a more common task of seeking a sustainable smart city [33]. In this way, a targeted literature analysis for weights' determination combined with expert's judgments followed to the prioritization of sustainable city development dimensions, such as living, environment, economy and productivity, governance, mobility and transportation, people and society, infrastructure, technology, and ICT. The study also highlights the question of the difference between experts' opinion and the average citizen's view; therefore, a holistic and long-term sustainability view should be taken.

Consumer-based simulation of vehicle replacement behaviour under various policy scenarios using a choice model showed that promotion alone had limited effectiveness in reducing particulate matter emissions [34]. The vehicle replacement model has been adapted in line with the stock market in the road transport sector and the combination of the probability of expected consumer choice between EV or a conventional vehicle with internal combustion engine (ICE). A study of a South Korean case assumed that the combination of applicable regulations on diesel vehicles and a targeted rebate can achieve a significant result in reducing emissions.

Studies conducted in different regions about the deployment of EVs frequently formulate similar conclusions, confirming that smooth EV diffusion in the market is subject of political decisions (i.e., applying adequate financial incentives), technological capabilities (i.e., preparing for intelligent management of the electricity grid and charging capacities), the financial capacity of society, and attitudes towards technology. However, despite common barriers to development, individual countries have rather specific regulations, technological capabilities, consumer attitudes, and expectations. As a result, this article analyses the situation of the Republic of Lithuania.

3. A Model for the Dynamics of EV Deployment in Lithuania

The first wave of EVs was at the early stage of road vehicle industry around the 1900s. The total number of EVs was higher than that of ICE-powered vehicles in the US [35]. However, this fact is remembered only historically as, soon after, ICE-powered vehicles became predominant subsequent to the invention of the starter motor and the beginning of the mass production of Ford Model T. Moreover, at that time, limited access to electricity and high prices had already stopped EV deployment. In the twentieth century, the automotive industry experienced several ups and downs, but only with the symbolic demonstrations of the electric drive until the mass production of hybrid electric vehicles (HEVs) began at the end of the century. The next century brought the further development of HEVs and their succeeding technological stage of PHEVs with the resurgence of full EVs. The market share of vehicles with different types of powertrains and the three forecast scenarios for EVs are shown in Figure 1.

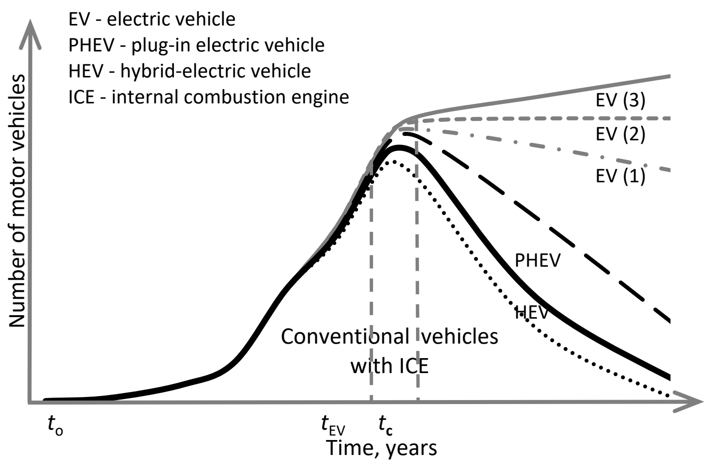

Figure 1. Dynamic model for the number of motor vehicles in the country considering different scenarios for electric vehicle deployment (t_o—start of manufacturing motor vehicles, t_{EV}—start of manufacturing electric vehicles, t_c—current time).

Three scenarios have been foreseen for EV deployment in the future (Figure 1): decreasing tendencies—EV (1); keeping constant—EV (2); and increasing—EV (3). The share of ICE-powered vehicles will constantly decrease, while the market share for HEVs and PHEVs is predicted to remain constant but significantly lower than that for EVs. The European Union (EU) plans to stop the production of conventional vehicles with ICE by 2035, but this date will be shifted by another 5–10 years for other regions of the world depending on the level of economic development of the country. This means that fossil fuel vehicles will still take their share of the road. Furthermore, the use of e-fuels will keep ICE-powered vehicles in the future market for niche brands; however, mass EV deployment is part of the transition to the next society (Society 5.0) as an element of smart transportation that the current generation is already facing [36]. The transition to EV will boost next-generation technologies, such as vehicle communication and autonomous transport; therefore, sustainable development is necessary.

In agreement with the data provided by the ACEA, EV manufacturing in Europe is approaching 15% (14.6% in consonance with the data collected for the period from January to July) of the market in 2023 [4]. In the first half of 2023, EVs sold in North America (together with PHEVs) accounted for 12% (growth of 50% compared to 2022), and in China, 5.2% (growth of 37%) [37]. According to data generated in Lithuania in 2023, the share of EVs (including PHEVs) among all cars is only 1% [34]. This indicates a huge difference between regions and individual states. Consequently, urgent but effective government decisions and their implementation measures are required for the faster deployment of ecological transport.

Decision makers, politicians, and developers most frequently suggest one or a few reasons for accelerating electric vehicle deployment nationwide, thus expressing their personal opinion or indicating the position of other experts in the field. The lack of scientifically based opinions expressed by the expert group allowed for quantifying the significance of all factors (criteria) compared with each other and, therefore, prompted this study. Thus, this article aims to present the hierarchy structure of the factors that have an effect on the deployment of EVs nationwide and to determine the significance of the factors by applying a subjective assessment made by experts using MCDM methods.

4. Factors Affecting EV Deployment in the Country

The experience gained by the authors of this paper, as well as analysis of research work, communication, and discussions with experts in the fields of road transport development and quality improvement, and analysis of legal acts, allowed for the systematisation of factors having an effect on the deployment of EVs in Lithuania. A total of 50 factors contributing to the deployment of EVs were identified, and the hierarchical structure was applied to process such a large number of factors. All factors were systematised in a three-level hierarchy structure (Figure 2): level 1 (aim) is made of EV deployment in the country, level 2 consists of seven main criteria (from A to G), and level 3 includes the sub-criteria, the number of which varies from 5 to 10 in the main criteria.

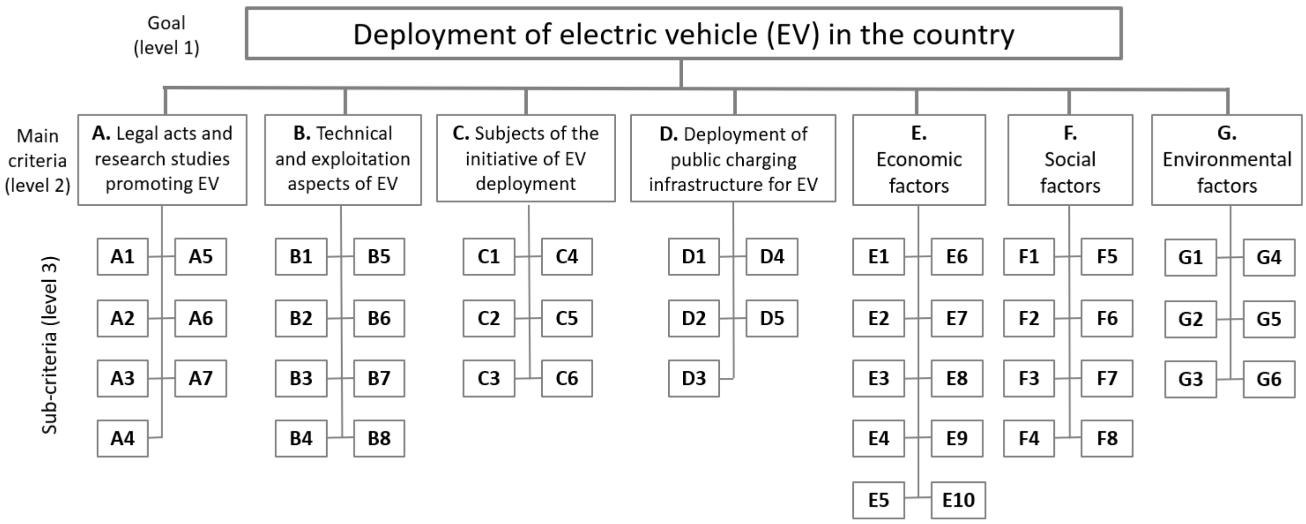

Figure 2. Hierarchy structure of the factors that affect the deployment of EV in the country.

The abbreviation (marking) and description of the main criteria and sub-criteria allowed the experts to understand the core of each factor and quantitatively evaluate the significance of the factor. The descriptions were formulated in the questionnaire prepared for expert evaluation and are given below.

Main criteria

A. The preparation of regulations on the evaluation of EV benefits, deployment, and exploitation manner.
B. Technical and exploitation parameters of the used electric vehicles.
C. The action of the initiative subjects for EV deployment.
D. The installation and development of infrastructure for public charging.
E. Economic factors.
F. Social factors.
G. Environmental factors.

Sub-criteria for main criterion A

A1. Complex projects and studies that establish the need and implementation possibilities of EV infrastructure deployment.
A2. Permissions set out in the traffic regulation for driving in a bus lane.
A3. Road signs and markings indicating that complying with traffic regulation road signs are not valid for EVs and have been put into use on the roads.
A4. Marking of EV parking spaces specified in traffic regulation.
A5. European safety and technical regulations on high-power charging stations.
A6. The preparation of a law regulating EV deployment and use.
A7. A roadmap to a single European transport area ('White paper on transport'); Paris Agreement in line with the UN Climate Change Conference; the documents prepared by the European Commission regulating the development of environmentally friendly transport; the resolutions of the Glasgow United Nations Climate Change Conference.

Sub-criteria for main criterion B

B1. EV manufacturer (brand), production, construction, and guarantee period.
B2. Battery durability determined by the number of potential charge–discharge cycles.
B3. EV driving comfort and ergonomics.
B4. EV driving range on one charge, EV driving safety, maximum speed, and dynamics (acceleration).
B5. An obligation to equip EVs with an acoustic vehicle alerting system.
B6. The relatively small size of EVs and simple use are advantages for driving in the city.
B7. Significantly increased energy consumption to heat the EV cabin in winter or cold climates.
B8. Long EV charging time (longer than the duration of refuelling fuel tank) and the ban on EV charging for an unlimited time from 2022.

Sub-criteria for main criterion C

C1. The initiative for state institutions (Ministry of Transport and Communications of the Republic of Lithuania, Ministry of the Economy and Innovations of the Republic of Lithuania, Municipalities, etc.).
C2. The initiative for private businessmen (legal entities operating in the EV deployment business).
C3. An individual initiative for residents (potential EV users).
C4. The establishment of the Electric Vehicle Association in Lithuania.
C5. The establishment of an international working group to promote EV transport activities in Lithuania.
C6. Initiative and active actions taken by EV manufacturers.

Sub-criteria for main criterion D

D1. The construction and development of low- and middle-power charging points (up to 22 kW, AC) and Type 2 charging connector.
D2. The construction and deployment of rapid charging points (more than 22 kW, DC).
D3. The lack of public charging points in the five largest cities and resorts of Lithuania and in the Trans-European Transport Network (TEN-T).

D4. The anticipation of public charging points in planned urban areas.
D5. The installation of low-power charging points in individual houses.

Sub-criteria for main criterion E

E1. The price of the installation of charging stations and underground cables (power inputs) for the power supply.
E2. Increasing prices and the probable (potential) shortage of electric energy in charging stations.
E3. Tax benefits and purchase incentives for EVs.
E4. Higher costs of manufacturing and purchasing EVs compared to the price for a fossil-fuel-powered vehicle.
E5. The price of electricity is lower than that of fuel consumed for the same driving range, which tends to increase.
E6. The high price of replacing a battery for a new one.
E7. The reluctance of business competitors to cooperate on non-discriminatory terms in EV deployment.
E8. The possibility of using excess pollution permits for EV deployment.
E9. Exemption from the EV parking fee in the charged parking slots.
E10. Lower costs of EV exploitation, rejecting the need to change engine oil and filter, slower wear of brake pads.

Sub-criteria for main criterion F

F1. Understanding that reducing environmental pollution is the responsibility of every citizen.
F2. The promotion of a positive attitude towards EV expansion in the environment, life quality, and demonstrations held by climate activists.
F3. The sense of exclusivity and innovation experienced by the EV owner.
F4. Positive attitude of friends, acquaintances, and authoritative persons towards EVs.
F5. Lower risk of an EV being stolen.
F6. EV suitability for car sharing in the city.
F7. Requirements for state employees driving EVs purchased for pollution permits.
F8. Teaching courses on EVs in colleges and universities.

Sub-criteria for main criterion G

G1. EVs do not emit any pollution into the air while driving.
G2. EVs do not separate liquids after a collision and, thus, do not pollute the roadside environment, e.g., soil or water.
G3. Increased ecology of EVs while using energy from nuclear, renewable, or hydroelectric power plant energy sources.
G4. Pollution from electricity production in power plants for EVs is lower than emissions from a conventional vehicle.
G5. The EV powertrain emits less noise (noise from tyres and aerodynamics is close to that of a conventional vehicle).
G6. Low efficiency in recycling technologies for lithium-ion batteries, complicated extinguishing, and high fire emissions.

The main criteria presented in the hierarchical structure (Figure 2) and each main criterion or sub-criterion are assessed separately applying expert evaluation methods.

Each expert was given a questionnaire made of two parts: the descriptions of the main criteria and sub-criteria that required ranking and eight matrix forms of the AHP method. The expert filled in the form comparing the pairs of the main criteria or sub-criteria. To fill in the pairwise comparison matrices of the AHP method, the expert had to meet the transitivity conditions. The average ranks of the main criteria and sub-criteria were used for calculating local weights applying Average Rank Transportation into Weight Linear (ARTIW-L) and Average Rank Transformation into Weight Nonlinear (ARTIW-N) methods [38]. The AHP method used each pairwise comparison matrix employed for calculating eigenvectors, meeting the normalised local weights of the main criteria or sub-criteria. Additionally, the consistency of each matrix was checked.

5. Research Methodology

5.1. Principles of Determining the Significance of the Criteria

Theory and practice suggest few ways of assessing the significance of object-oriented indicators (factors, properties), called the criteria. Criterion ranking is one of the most popular and simplest methods [39]. Direct evaluation of criterion weights in percentages [40] or in parts of a unit is also frequently applied. In other cases, the weights of the criteria are determined indirectly.

Three MCDM methods, including ARTIW-L, ARTIW-N, and AHP, were applied for studying the significance of the main criteria and sub-criteria affecting EV deployment in the country. The employed methods assist in determining the significance of the main criteria and sub-criteria considering expert opinions expressed as ranks and the elements of pairwise comparison matrices indicating their mutual intensity on a nine-point scale.

The methods used verified the consistency of the opinion of each expert in 96 pairwise comparison matrices of the criteria for the AHP method (calculating consistency ratio C.R) and validated the consistency of the opinions of 12 experts evaluating the main criteria and sub-criteria using the Kendall rank correlation method (calculating the coefficient of concordance W). None of these methods have a theoretical advantage over the other methods, while the most popular but most complicated is the AHP method.

The general principle of the algorithms of all these methods is the same; the most important criterion must be assigned the highest weight. The magnitudes of the weights (values) must correspond to the ranks of the criteria, where a lower rank takes a higher weight. The sum of the weights of all criteria must be equal to 1, that is, the weights are normalised.

5.2. ARTIW-L Method

This method allows for converting the averages of criterion ranks into normalised weights. The normalised subjective weight $\omega_i^{\mathrm{ARTIW-L}}$ of each criterion is calculated from the following formula:

$$\omega_i^{\mathrm{ARTIW-L}} = \frac{(m+1) - \overline{R}_i}{\sum_{i=1}^{m} \overline{R}_i}, \tag{1}$$

Here, m—the number of the main criteria describing the research object (EV deployment in the country) or the number of the sub-criteria making any main criterion (i = 1, 2, . . ., m); $\overline{R}_i$—the average of the ranks of the main criterion or sub-criterion (given by the experts):

$$\overline{R}_i = \frac{\sum_{j=1}^{n} R_{ij}}{n}, \tag{2}$$

Here, n—the number of the experts evaluating the significance of the main criteria or sub-criteria (j = 1, 2, . . ., n); R_{ij}—the rank of the i-th criterion given by the j-th expert.

A highly correlated linear inverse relationship between weight $\omega_i^{\mathrm{ARTIW-L}}$ and the average of ranks $\overline{R}_i$ shows the functional dependence of the above significance estimates when the coefficient of determination R^2 = 1.

5.3. Consistency of the Opinions of the Expert Group

The average of the opinions (ranks or weights) of the expert group is used as a result of solving the problem only when these opinions are consistent, that is, noncontradictory [38]. The degree of consistency of the opinions of the expert group is expressed by Kendall's coefficient of concordance W calculated from the following formula [39]:

$$W = \frac{12S}{n^2(m^3 - m)}. \tag{3}$$

The sum of the squares S of the deviations of the sum of the ranks $\sum_{j=1}^{n} R_{ij}$ for each m-th criterion from the average rank $\overline{R}$ is calculated from the following formula:

$$S = \sum_{i=1}^{m} \left[\sum_{j=1}^{n} R_{ij} - \overline{R} \right]^2, \tag{4}$$

Here, $\overline{R}$—the average rank subject to the number of criteria m and the number of experts n:

$$\overline{R} = \frac{1}{2} n(m+1). \tag{5}$$

The calculated numerical value of the coefficient of concordance W does not specifically show the consistency of expert evaluations if it is not compared to the critical value. The coefficient of concordance W is applied in practice if the limit (threshold) value of the coefficient is set and writes down when the evaluations of the expert group are considered consistent (non-contradictory). Kendall [41] proved that when the number of objects (criteria) is $m \geq 7$, the significance of the coefficient of concordance is found using the χ^2 (chi-square) criterion. Random size:

$$\chi^2 = Wn(m-1), \tag{6}$$

is distributed conforming to χ^2 distribution, having a degree of freedom $\nu = m - 1$. In line with the selected level of significance α (in practice, the accepted value of α makes 0.05 or stricter 0.01), critical value $\chi^2_{\nu,\alpha}$ is found from the table of χ^2 distribution [42] with a degree of freedom $\nu = m - 1$. If the value of χ^2 calculated in consonance to Formula (6) is higher than $\chi^2_{\nu,\alpha}$, it is considered that expert evaluations are consistent.

When the number of comparable indicators (objects, criteria) m varies from 3 to 7, χ^2 distribution should be applied with caution, because its critical (threshold) value $\chi^2_{\nu,\alpha}$ may be higher than the calculated value of χ^2, although the consistency level of expert opinions is sufficient. In this case ($3 \leq m \leq 7$), it is possible to apply the probability tables of the coefficient of concordance when $3 \leq m \leq 7$ or the tables of critical values S [42].

It is convenient to calculate the minimum threshold value of the coefficient of concordance $W_{\min}$, for which it is reasonable to consider (accept) that the opinions of the expert group are consistent (non-contradictory) [43]:

$$W_{\min} = \frac{\chi^2_{\nu,\alpha}}{n(m-1)}, \tag{7}$$

Here, $\chi^2_{\nu,\alpha}$—the threshold value of the statistics of the Pearson criterion found in the table of mathematical statistics [44].

The research finds it important to determine both the fact proving that the opinions of the expert group are consistent or not consistent and the degree of consistency. For this purpose, the consistency coefficient is used:

$$k_c = \frac{\chi^2}{\chi^2_{\nu,\alpha}} = \frac{W}{W_{\min}}. \tag{8}$$

When k_c is greater than 1, the opinions of the expert group are consistent.

By comparing calculated k_c and its highest possible value $k_{c\max}$ agreeing with the total uniformity of the opinions of all experts in the group ($W = 1$), it is possible to quantify the actual relative consistency of expert opinions $k_c/k_{c\max}$. The maximum possible value of the consistency coefficient is calculated from the following formula:

$$k_{c\max} = \frac{W_{\max}}{W_{\min}} = \frac{1}{W_{\min}}. \tag{9}$$

The ratio of k_c and $k_{c\max}$ shows the proportion of the actual degree of consistency of expert opinions to the maximum possible degree of consistency.

5.4. ARTIW-N Method

The normalised weights of the main criteria and sub-criteria are calculated applying the Average Rank Transformation into Weight Nonlinear (ARTIW-N) method. The weights calculated in line with Formulas (10) and (11) and with rank averages $\overline{R}_i$ are linked by a nonlinear inverse correlation (very close to functional dependence). Therefore, this method is called ARTIW-Nonlinear [38].

The ARTIW-N method calculates a relationship between the most important criterion having the lowest average rank $\min\limits_i \overline{R}_i$, and the average of the ranks of each criterion $\overline{R}_i$:

$$u_i = \frac{\min\limits_i \overline{R}_i}{\overline{R}_i}. \tag{10}$$

The normalised weight of the main criterion or sub-criterion is obtained dividing the weight u_i of each main criterion or sub-criterion by the sum of weights:

$$\omega_i^{\text{ARTIW}-\text{N}} = \frac{u_i}{\sum_{i=1}^{m} u_i}. \tag{11}$$

A correlation between $\overline{R}_i$ and $\omega_i^{\text{ARTIW}-\text{N}}$ shows a comparison of ARTIW-N and ARTIW-L methods and points to an 'increase' in the significance (weight) of the most and least important criteria, thus 'decreasing' the weights of the medium-importance criteria.

5.5. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) developed by T. Saaty is the most widely used MCDM method for determining criterion weights and comparing alternatives. The core of the technique is a pairwise comparison of the criteria [45]. The criteria arranged at the beginning are compared in pairs employing a nine-point mutual intensity scale. A square pairwise comparison matrix of criteria $\mathbf{A} = \|a_{ij}\|_{m\times m}$ ($i = 1, 2, \ldots, m$) is filled, whose elements a_{ij} vary from 1/9 to 9. Values a_{ij} provided in the pairwise comparison matrix of the factors (criteria) indicate the predominance of the left-sided criterion in terms of the criterion on the top of the matrix.

The AHP method is convenient due to the fact that it is easier for the expert to compare a pair of criteria that have an effect on EV deployment in the country rather than comparing all criteria at once. The pairwise comparison of the criteria is simple and reliable only for an expert well versed in the AHP method. A necessary condition for the consistency of the criterion comparison matrix is the transitivity of the importance of the elements of the matrix. The help of a researcher conducting the research is welcomed to monitor whether the transitivity condition is not violated in the filling process.

The pairwise comparison matrix of the criteria evaluated by a single expert is reciprocal, i.e., $a_{ij} = \frac{1}{a_{ji}}$. In fact, $a_{ij} = \frac{\omega_i}{\omega_j}$ and $a_{ji} = \frac{\omega_j}{\omega_i}$:

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2m} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots & \vdots\vdots\vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{im} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots & \vdots\vdots\vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mj} & \cdots & a_{mm} \end{bmatrix}. \tag{12}$$

In practice, the transitivity condition eases the identification of the contradictory matrices filled in the examination questionnaire. In this case, this condition is hardly satisfied (invalid). An inconsistent matrix is rejected or corrected by an expert or examiner.

The most exact algorithm for finding the relative significance (importance) of the approximate criteria expressed by normalised weights ω_i^{AHP} is based on the calculation of the geometric averages of the products of the row elements a_{ij} of the pairwise comparison matrix [46–49]:

$$\omega_i^{\mathrm{AHP}} = \frac{\sqrt[m]{\prod_{j=1}^{m} a_{ij}}}{\sum_{i=1}^{m} \sqrt[m]{\prod_{j=1}^{m} a_{ij}}} (i = 1, 2, \ldots, m). \tag{13}$$

Having normalised the roots of the m-th degree of the products of the row elements a_{ij} in the pairwise comparison matrix, the eigenvector, ω_i^{AHP}, is calculated, which is reasonably taken (considered) as criterion weights representing the opinion of a single expert.

The consistency of matrix **A** in the pairwise comparison of the criteria satisfying transitivity conditions is verified by calculating the largest eigenvalue:

$$\lambda_{\max} = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{\sum_{j=1}^{m} a_{ij}\omega_j}{\omega_i^{\mathrm{AHP}}}. \tag{14}$$

The largest determined eigenvalue of the reciprocal matrix in the m-th row equals $\lambda_{\max} \geq m$. When the pairwise comparison matrix of the criteria is entirely consistent, the elements of the columns of matrix a_{ij} are proportional and $\lambda_{\max} = m$. The consistency of the matrix is shown by the ratio of difference $\lambda_{\max} - m$ to the number of the criteria evaluated in matrix $m - 1$, called the consistency index ($C.I.$):

$$C.I. = \frac{\lambda_{\max} - m}{m - 1}. \tag{15}$$

A pairwise comparison matrix of the criteria ($C.I. = 0$) is very rarely obtained in practice and even in cases when the transitivity condition of matrix elements is fully satisfied. Quantitatively, the degree of matrix consistency is determined by dividing the consistency index $C.I.$ from the random index $R.I.$ The value of the random index ($R.I.$) depends on the row of matrix m and is found in the table [45] or calculated in line with the following formula [50]:

$$R.I. = 1.98 \frac{m - 2}{m}. \tag{16}$$

The consistency ratio ($C.R.$) of the matrix is calculated conforming to the following formula:

$$C.R. = \frac{C.I.}{R.I.} = \frac{\lambda_{\max} - m}{(m - 1)R.I.}. \tag{17}$$

A matrix is reasonably considered consistent when the calculated $C.R.$ is lower or equal to 0.1, i.e., 10% [45] (0.2 may be tolerated, but not more) [51]. An inconsistency of 10% or less implies that the adjustment is small compared to the actual values of the eigenvector entries [52].

The AHP method is highly efficient in determining the weights of the research object consisting of seven criteria. The numbers of criteria from 5 to 9 are also considered suitable for the AHP method [53,54].

5.6. The Average of the Local Weights of the Main Criteria and Sub-Criteria

The local weights of the sub-criteria calculated employing three different MCDM methods usually vary. None of the MCDM methods have a theoretical advantage over the other methods; therefore, the local weighted average of each main criterion or sub-criterion $\overline{Q}_{i,mc}$ and $\widetilde{\omega}_{il}$ was calculated using three methods, which is more reliable than the weight calculated employing one methods. Without giving preference to individual MCDM methods, the arithmetic mean of the local weights of the i-th sub-criterion is calculated in consonance with the following formula:

$$\widetilde{\omega}_{il} = \frac{\omega_i^{\text{ARTIW}-\text{L}} + \omega_i^{\text{ARTIW}-\text{N}} + \overline{\omega}_i^{AHP}}{3}, \quad (18)$$

Here, $\omega_i^{\text{ARTIW}-\text{L}}$, $\omega_i^{\text{ARTIW}-\text{N}}$, $\overline{\omega}_i^{AHP}$—the normalised local weight (eigenvector) of the i-th sub-criterion calculated using ARTIW-L, ARTIW-N and AHP methods, respectively.

All local weights of the sub-criteria regarding the main criteria for the hierarchical structure of EV deployment in the country are calculated separately.

5.7. Calculating the Global Weights of the Sub-Criteria

The significance of all factors affecting EV deployment in the country is established calculating the global weight ω_{ig} of each sub-criterion. For this purpose, the local weights of the main criteria, the sub-criteria forming the main criteria, and the size of the main criteria (the number of the sub-criteria in the main criteria) are evaluated:

$$\omega_{ig} = \frac{\overline{Q}_{i,mc} \cdot \widetilde{\omega}_{il} \cdot m_{i,mc}}{\sum_{i=1}^{m} \overline{Q}_{i,mc} \cdot \widetilde{\omega}_{il} \cdot m_{i,mc}}, \quad (19)$$

Here, $\overline{Q}_{i,mc}$—the normalised weight of the i-th main criterion determined using three MCDM methods; $\widetilde{\omega}_{il}$—the average of the local weight of the i-th sub-criterion calculated using three MCDM methods; $m_{i,mc}$—the number of the sub-criteria making the i-th main criterion; m—the number of main criteria (i = 1, 2, . . . m).

Formula (19) shows that the main criterion and the sub-criterion forming the main criterion are more important, and the higher the normalised global weight ω_{ig} of the sub-criterion is. As for the country of EV deployment, decision makers, in order to keep up with the rapid pace of development, must use the factors (sub-criteria) with the largest global weights in priority order.

6. Experts

Twelve specialists in the field of transport engineering were selected for this research who had achieved significant practical results in the sector of road transport system research and development. It is worth noting that 11 of them have doctoral degrees in science, and 1 is the head of a representative office of a well-known vehicle manufacturer. The experts agreed to rank the criteria given in the questionnaire and complete eight pairwise comparison matrices, taking 1.5 to 2 h. The opinions of each expert were not affected by the authors of this article. The authors assembled the team of experts, aware of the competences of each expert and the practical or academic background. All of them are familiar with the basic principles of the AHP method and with completing the required matrix and adequately assessing the application of such methods in terms of EV deployment.

7. Results and Discussion

7.1. The Ranks of the Main Criteria and Sub-Criteria and the Consistency of Expert Opinions

The significance of the main criteria and the sub-criteria forming the main criteria calculated by the rank correlation method is different. Experts agree that the main criterion D evaluates the development of EV public charging infrastructure and has an average rank of $\overline{R}_D = 2.583$. The main criterion for evaluating economic factors is also very important and has an average rank of $\overline{R}_E = 3.333$. The third position is taken by the main criterion evaluating the technical and operational parameters for the used EVs and holds an average rank of $\overline{R}_B = 3.417$. Experts suppose that ecological (environmental) factors are among the most important main criteria and occupy the fourth position, with the average of ranks reaching $\overline{R}_G = 3.75$ (Figure 3). Social factors have the least influence on EV deployment in the country ($\overline{R}_F = 6.25$).

Rank	$\overline{R_A} = 4.417$	$\overline{R_B} = 3.417$	$\overline{R_C} = 4.25$	$\overline{R_D} = 2.583$	$\overline{R_E} = 3.333$	$\overline{R_F} = 6.25$	$\overline{R_G} = 3.75$
Priority	6	3	5	1	2	7	4

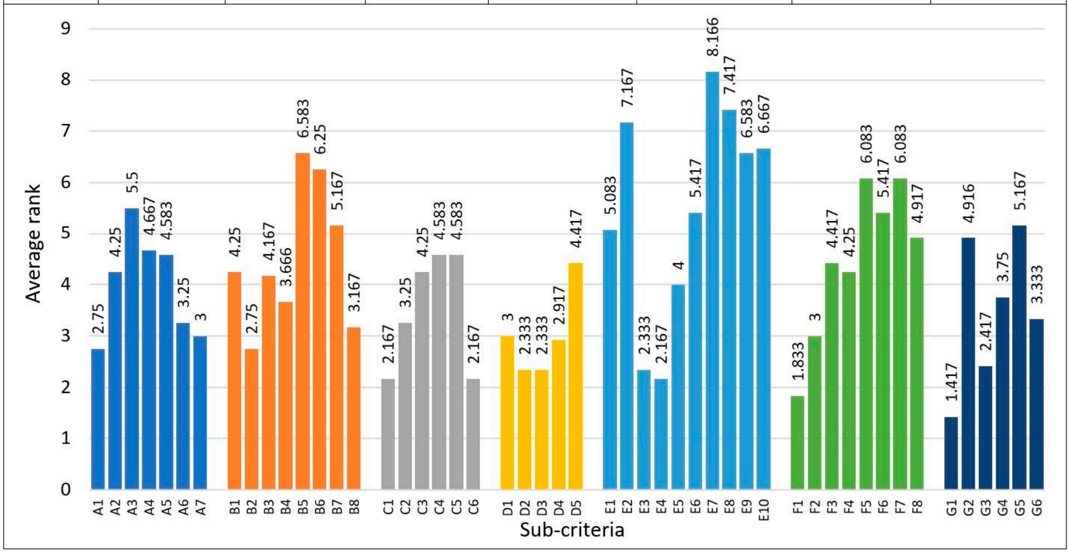

Figure 3. The average rank and priority of the main criteria and sub-criteria for EV deployment in the country.

In order for the average rank $\overline{R}_i$ to be reasonably taken as a solution to the problem indicated by the expert group, the opinions of all 12 experts involved in the examination process were consistent, although with some differences. The coefficient of concordance of the main criteria is $W = 0.2912$, whereas its lowest value at which the significance level of $\alpha = 0.05$ is still considered consistent equals $W_{\min} = 0.1749$, i.e., the ratio is called the consistency coefficient $k_c = 1.665$ (Table 1).

Table 1. The results of calculating the consistency of the ranks given by experts to the main criteria and sub-criteria that affect the deployment of EVs in the country, when $\alpha = 0.05$.

Statistics	Main Criteria from A to G	Sub-Criteria $i = 1, 2, \ldots, m$						
		A1, . . ., A7	B1, . . ., B8	C1, . . ., C6	D1, . . ., D5	E1, . . ., E10	F1, . . ., F8	G1, . . ., G6
W	0.2912	0.2222	0.3228	0.3730	0.2903	0.4810	0.3681	0.5937
$W_{\min}$	0.1749	0.1749	0.1675	0.1845	0.1977	0.1567	0.1675	0.1845
χ^2	20.96	16.00	27.11	22.38	13.93	51.93	30.92	35.62
$\chi^2_{\nu,\alpha}$	12.59	12.59	14.07	11.07	9.49	16.92	14.07	11.07
k_c	1.665	1.271	1.927	2.022	1.468	3.070	2.200	3.218
$k_{c\max}$	5.72	5.72	5.97	5.42	5.06	6.38	5.97	5.42
$\frac{k_c}{k_{c\max}}$	0.29	0.22	0.32	0.37	0.29	0.48	0.37	0.59

The ranks of the sub-criteria for each main criterion (A, . . ., G) are also consistent, and the coefficient of concordance fluctuates from 0.2222 (sub-criteria A1, . . ., A7) to 0.5937 (sub-criteria G1, . . ., G6) and must be higher than 0.1749 and 0.1845, respectively. The consistency of expert opinions on evaluating sub-criteria A1, . . ., A7 is the worst ($k_c = 1.271$) while that on sub-criteria G1, . . ., G6 is the best ($k_c = 3.218$). This is shown by the calculated values of $k_c/k_{c\max}$ equalling 0.22 and 0.59, respectively (Table 1).

The sufficient consistency of the opinions of all 12 experts involved in this study allowed for the arithmetic means of the ranks and weights indicating the significance of the main criteria and sub-criteria to be used as the generalized opinion of the expert group.

For applying the AHP method, a key point is the consistency of each pairwise comparison matrix of the main criteria and sub-criteria, i.e., $C.R.$ would not exceed 0.1. The minimum and maximum values of the $C.R.$ given in pairwise comparison matrices are provided in Table 2, showing that only a single matrix out of 96 was inconsistent under $C.R. = 0.1103$. Since its $C.R.$ is slightly higher than 0.1 but lower than 0.2, the weights ω_i^{AHP} of F1, . . ., F8 figured out by this expert were used in this study with a small error and no reason to be rejected.

Table 2. The values of the consistency ratio $C.R.$ of the pairwise comparison matrices of main criteria and sub-criteria calculated applying the AHP method.

C.R.	Main Criteria from A to G	Sub-Criteria						
		A1, . . ., A7	B1, . . ., B8	C1, . . ., C6	D1, . . ., D5	E1, . . ., E10	F1, . . ., F8	G1, . . ., G6
min	0.0080	0.0173	0.0124	0.0097	0.0082	0.0301	0.0218	0.0131
max	0.0803	0.0893	0.0826	0.0712	0.0780	0.0998	0.1103	0.0920

7.2. Local Weights Calculated Using Different MCDM Methods

The subjective normalised weights of the main criteria calculated applying the ARTIW-L, ARTIW-N and AHP methods are slightly different. However, their priority is the same. The arithmetic mean of the weights of the main criteria $\overline{Q}_{i,mc}$ calculated employing three MCDM methods shows that the main criteria D, E and B are the most important and make $\overline{Q}_{D,mc} = 0.2059$, $\overline{Q}_{E,mc} = 0.1648$ and $\overline{Q}_{B,mc} = 0.1633$, respectively (Table 3). Regarding the deployment of EVs in the country, experts suggest that ecological (environmental) factors take only the fourth position ($\overline{Q}_{G,mc} = 0.1523$). The weight of the most important main criterion $\overline{Q}_{D,mc} = 0.2059$ is 3.07-times higher than the weight of the least important social factors (criteria) $\overline{Q}_{F,mc} = 0.067$.

Table 3. The local weights of the main criteria for the deployment of EV in the country determined using different methods and their priority.

MCDM Method	Main Criteria $i = 1, 2, \ldots, m$						
	A	B	C	D	E	F	G
$\omega_{i,mc}^{\mathrm{ARTIW-L}}$	0.1280	0.1637	0.1339	0.1934	0.1667	0.0625	0.1518
$\omega_{i,mc}^{\mathrm{ARTIW-N}}$	0.1212	0.1567	0.1260	0.2072	0.1606	0.0856	0.1427
$\overline{Q}_{i,mc}^{\mathrm{AHP}}$	0.1187	0.1694	0.1123	0.2172	0.1672	0.0530	0.1622
$\overline{Q}_{i,mc}$	0.1226	0.1633	0.1241	0.2059	0.1648	0.0670	0.1523
Priority	6	3	5	1	2	7	4

The local weights of all sub-criteria for each main criterion determined using different MCDM methods and the calculated arithmetic means and priorities are presented in Tables 4–10.

Table 11 compares the maximum (max) $Q_{mc\ \max}$ ($\omega_{il\ \max}$) and minimum (min) $Q_{mc\ \min}$ ($\omega_{il\ \min}$) values of the local weights of the main criteria and sub-criteria in line with their differences ΔQ_{mc} or $\Delta\omega_{il}$. They indicate the varying sensitivity of three MCDM methods. The greater the difference, the more important the most significant criteria and the less important the criteria having the lowest value of the local weight of EV deployment in the country. The data provided in Table 11 show that the largest difference in local weights is obtained using the AHP method. Thus, there is a tendency that the least 'sensitive' of the three MCDM methods is ARTIW-L applied for calculating the smallest difference ΔQ_{mc} and $\Delta\omega_{il}$ in the highest $Q_{mc\ \max}$ ($\omega_{il\ \max}$) and lowest $Q_{mc\ \min}$ ($\omega_{il\ \min}$) local weights of the criteria.

Table 4. The importance of legal acts and other documents that have an effect on the deployment of EVs.

MCDM Method	**Sub-Criteria** i **= 1, 2, . . ., m**						
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**
$\omega_i^{\text{ARTIW}-\text{L}}$	0.1875	0.1339	0.0893	0.1190	0.1220	0.1697	0.1786
$\omega_i^{\text{ARTIW}-\text{N}}$	0.1961	0.1269	0.0980	0.1156	0.1177	0.1659	0.1798
$\overline{\omega}_i^{\text{AHP}}$	0.2107	0.1039	0.0824	0.1105	0.1149	0.1771	0.2005
$\widetilde{\omega}_{Ail}$	0.1981	0.1216	0.0899	0.1150	0.1182	0.1709	0.1863
Priority	1	4	7	6	5	3	2

Table 5. The significance of technical and operational parameters for EV deployment.

MCDM Method	**Sub-Criteria** i **= 1, 2, . . ., m**							
	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
$\omega_i^{\text{ARTIW}-\text{L}}$	0.1319	0.1736	0.1343	0.1482	0.0671	0.0764	0.1065	0.1620
$\omega_i^{\text{ARTIW}-\text{N}}$	0.1217	0.1881	0.1242	0.1411	0.0786	0.0828	0.1001	0.1634
$\overline{\omega}_i^{\text{AHP}}$	0.1198	0.2026	0.1439	0.1649	0.0545	0.0586	0.0826	0.1731
$\widetilde{\omega}_{Bil}$	0.1245	0.1881	0.1341	0.1514	0.0667	0.0726	0.0964	0.1662
Priority	5	1	4	3	8	7	6	2

Table 6. The importance of the activities of the initiative to develop EV and to have an effect on the deployment of electric vehicles.

MCDM Method	**Sub-Criteria** i **= 1, 2, . . ., m**					
	C1	**C2**	**C3**	**C4**	**C5**	**C6**
$\omega_i^{\text{ARTIW}-\text{L}}$	0.2301	0.1786	0.1310	0.1151	0.1151	0.2301
$\omega_i^{\text{ARTIW}-\text{N}}$	0.2426	0.1617	0.1237	0.1147	0.1147	0.2426
$\overline{\omega}_i^{\text{AHP}}$	0.2915	0.1536	0.1030	0.0895	0.0827	0.2797
$\widetilde{\omega}_{Cil}$	0.2547	0.1646	0.1192	0.1065	0.1042	0.2508
Priority	1	3	4	5	6	2

Table 7. The significance of installing public charging infrastructure and development factors that have an effect on EV deployment.

MCDM Method	**Sub-Criteria** i **= 1, 2, . . ., m**				
	D1	**D2**	**D3**	**D4**	**D5**
$\omega_i^{\text{ARTIW}-\text{L}}$	0.2000	0.2445	0.2445	0.2055	0.1055
$\omega_i^{\text{ARTIW}-\text{N}}$	0.1894	0.2436	0.2436	0.1948	0.1286
$\overline{\omega}_i^{\text{AHP}}$	0.1858	0.3109	0.2444	0.1802	0.0787
$\widetilde{\omega}_{Dil}$	0.1917	0.2663	0.2442	0.1935	0.1043
Priority	4	1	2	3	5

Table 8. The importance of economic factors having an effect on EV deployment.

MCDM Method	Sub-Criteria i = 1, 2, ..., m									
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**
$\omega_i^{\text{ARTIW-L}}$	0.1076	0.0697	0.1576	0.1606	0.1273	0.1015	0.0515	0.0651	0.0803	0.0788
$\omega_i^{\text{ARTIW-N}}$	0.0886	0.0629	0.1931	0.2078	0.1126	0.0831	0.0552	0.0607	0.0684	0.0676
$\overline{\omega}_i^{\text{AHP}}$	0.0992	0.0578	0.2089	0.2075	0.1281	0.0835	0.0332	0.0497	0.0702	0.0619
$\widetilde{\omega}_{Eil}$	0.0985	0.0634	0.1865	0.1920	0.1227	0.0894	0.0466	0.0585	0.0730	0.0694
Priority	4	8	2	1	3	5	10	9	6	7

Table 9. The significance of social factors having an effect on the deployment of EVs.

MCDM Method	Sub-Criteria i = 1, 2, ..., m							
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**
$\omega_i^{\text{ARTIW-L}}$	0.1991	0.1667	0.1273	0.1320	0.0810	0.0995	0.0810	0.1134
$\omega_i^{\text{ARTIW-N}}$	0.2652	0.1620	0.1100	0.1144	0.0799	0.0897	0.0799	0.0989
$\overline{\omega}_i^{\text{AHP}}$	0.2561	0.1888	0.1278	0.1217	0.0539	0.0834	0.0564	0.1119
$\widetilde{\omega}_{Fil}$	0.2401	0.1725	0.1217	0.1227	0.0716	0.0909	0.0724	0.1081
Priority	1	2	4	3	8	6	7	5

Table 10. The significance of environmental factors having an effect on EV deployment.

MCDM Method	Sub-Criteria i = 1, 2, ..., m					
	G1	**G2**	**G3**	**G4**	**G5**	**G6**
$\omega_i^{\text{ARTIW-L}}$	0.2659	0.0992	0.2182	0.1548	0.0873	0.1746
$\omega_i^{\text{ARTIW-N}}$	0.3388	0.0976	0.1986	0.1281	0.0929	0.1440
$\overline{\omega}_i^{\text{AHP}}$	0.3311	0.0904	0.2383	0.1227	0.0569	0.1606
$\widetilde{\omega}_{Gil}$	0.3119	0.0957	0.2184	0.1352	0.0790	0.1598
Priority	1	5	2	4	6	3

The significance of preparing legal acts and other documents assessing the benefits of EVs, promoting EV deployment, and determining the order of utility slightly differs. Experts suggest that sub-criterion A1 is the most important of the seven sub-criteria for the main criterion A. This criterion evaluates the importance of integrated EV deployment projects and studies determining the need for EV communication infrastructure and implementation possibilities (local weight equals $\widetilde{\omega}_{A1l} = 0.1981$). The least important is sub-criterion A3 (local weight makes $\widetilde{\omega}_{A3l} = 0.0899$), which is 2.2-times less significant than sub-criterion A1 (Tables 4 and 11).

The significance of the technical and operational parameters of the EV for the deployment of EVs in the country is expressed by the weights $\widetilde{\omega}_{Bil}$ of eight sub-criteria and the priorities of the main criterion B (Table 5). In this case, sub-criterion B2 is the most important ($\widetilde{\omega}_{B2l} = 0.1881$) as it evaluates the durability of the used battery, i.e., the possible number of charge–discharge cycles. The least significant sub-criterion B5 assesses the need for EV-installed external speakers emitting noise audible to pedestrians (Acoustic Vehicle Alerting System). The local weight of the sub-criterion is $\widetilde{\omega}_{B5l} = 0.0667$, which is around 2.82-times lower than the weight of sub-criterion B2.

The local weights $\widetilde{\omega}_{Cil}$ and priorities of the subjects of the initiative for developing EV manufacturing and the installation of public charging infrastructure (charging access) are presented in Table 6. The experts found that the sub-criterion C1 evaluating the initiative of state institutions is the most important ($\widetilde{\omega}_{C1l} = 0.2547$), whereas the least important sub-criterion C5 ($\widetilde{\omega}_{C5l} = 0.1042$) evaluated the creation of an inter-institutional working group promoting EV transport activities in Lithuania. The ratio of the local weights of the most important sub-criterion C1 to the least important sub-criterion C5 is 2.44.

Table 11. Differences between the maximum and minimum values of the local weights of the main criteria and sub-criteria calculated using various MCDM methods and having an effect on EV deployment.

Main Criteria and Sub-Criteria	Maximum, Minimum Weight, and the Difference in Weights	Method			Average of Three Methods
		ARTIW-L	ARTIW-N	AHP	
Main criteria	$Q_{mc\ \max}$	0.1934 (D)	0.2072 (D)	0.2172 (D)	0.2059 (D)
	$Q_{mc\ \min}$	0.0625 (F)	0.0856 (F)	0.0530 (F)	0.0670 (F)
	ΔQ_{mc}	0.1309	0.1216	0.1642	0.1389
Sub-criteria for the main criterion A	$\omega_{Ail\ \max}$	0.1875 (A1)	0.1961 (A1)	0.2107 (A1)	0.1981 (A1)
	$\omega_{Ail\ \min}$	0.0893 (A3)	0.0980 (A3)	0.0824 (A3)	0.0899 (A3)
	$\Delta\omega_{Ail}$	0.0982	0.0981	0.1283	0.1082
Sub-criteria for the main criterion B	$\omega_{Bil\ \max}$	0.1736 (B2)	0.1881 (B2)	0.2026 (B2)	0.1881 (B2)
	$\omega_{Bil\ \min}$	0.0671 (B5)	0.0786 (B5)	0.0545 (B5)	0.0726 (B5)
	$\Delta\omega_{Bil}$	0.1065	0.1095	0.1481	0.1155
Sub-criteria for the main criterion C	$\omega_{Cil\ \max}$	0.2301 (C1, C6)	0.2426 (C1, C6)	0.2915 (C1)	0.2547 (C1)
	$\omega_{Cil\ \min}$	0.1151 (C4, C5)	0.1147 (C4, C5)	0.0827 (C5)	0.1042 (C5)
	$\Delta\omega_{Cil}$	0.1150	0.1279	0.2088	0.1505
Sub-criteria for the main criterion D	$\omega_{Dil\ \max}$	0.2445 (D2, D3)	0.2436 (D2, D3)	0.3109 (D2)	0.2663 (D2)
	$\omega_{Dil\ \min}$	0.1055 (D5)	0.1286 (D5)	0.0787 (D5)	0.1043 (D5)
	$\Delta\omega_{Dil}$	0.1390	0.1150	0.2322	0.1620
Sub-criteria for the main criterion E	$\omega_{Eil\ \max}$	0.1606 (E4)	0.2078 (E4)	0.2089 (E3)	0.1920 (E4)
	$\omega_{Eil\ \min}$	0.0515 (E7)	0.0552 (E7)	0.0332 (E7)	0.0466 (E7)
	$\Delta\omega_{Eil}$	0.1091	0.1526	0.1757	0.1454
Sub-criteria for the main criterion F	$\omega_{Fil\ \max}$	0.1991 (F1)	0.2652 (F1)	0.2561 (F1)	0.2401 (F1)
	$\omega_{Fil\ \min}$	0.0810 (F5, F7)	0.0799 (F5, F7)	0.0539 (F5)	0.0716 (F5)
	$\Delta\omega_{Fil}$	0.1181	0.1853	0.2022	0.1685
Sub-criteria for the main criterion G	$\omega_{Gil\ \max}$	0.2659 (G1)	0.3388 (G1)	0.3311 (G1)	0.3119 (G1)
	$\omega_{Gil\ \min}$	0.0873 (G5)	0.0929 (G5)	0.0569 (G5)	0.0790 (G5)
	$\Delta\omega_{Gil}$	0.1786	0.2459	0.2742	0.2329

The local weights and priorities of five sub-criteria for the main criterion D for the installation and development of public EV charging infrastructure (park of charging points and stations) point out sub-criterion D2 as the most important ($\widetilde{\omega}_{D2l} = 0.2663$). The criterion evaluates the importance of installing and developing high-power DC access for fast charging. The least important sub-criterion D5 ($\widetilde{\omega}_{D5l} = 0.1043$) evaluates the installation of access for slow charging at standard power in individual houses (Table 7). The ratio of the local weights of the latter sub-criteria is 2.55.

The significance of economic factors for EV deployment in the country is expressed by the calculated weights and priorities of 10 sub-criteria and is given in Table 8. The calculations show that the experts accept sub-criterion E4 as the most important (local weight is $\widetilde{\omega}_{E4l} = 0.1920$), because it evaluates the cost of the manufacture and purchase of EVs, which is higher than the price of a vehicle with ICE. As for the economic sub-criteria, the least important is E7 (local weight is $\widetilde{\omega}_{E7l} = 0.0466$). The sub-criterion evaluates the reluctance of competitors working in the vehicle business to cooperate under non-discriminatory conditions of EV deployment. The ratio of the local weights of these sub-criteria is 4.12, which is the highest among all main criteria and shows the greatest difference in significance decided by the experts. The local weights $\widetilde{\omega}_{Fil}$ and priorities of eight social sub-criteria affecting EV deployment in the country are given in Table 9.

The provided data suggest sub-criterion F1 as the most important ($\widetilde{\omega}_{F1l} = 0.2401$) as it evaluates the belief that reducing environmental pollution is the responsibility of every citizen. The social experts agree on sub-criterion F5 as the least important that evaluates the lower probability of EV theft ($\widetilde{\omega}_{F5l} = 0.0716$). The ratio of $\widetilde{\omega}_{F1l}$ to $\widetilde{\omega}_{F5l}$ is 3.35.

The significance of the ecological (environmental) factors making up the main criterion G for EV deployment in the country is shown by six sub-criteria. The local weights and priorities of these sub-criteria are given in Table 10. Sub-criterion G1 is the most important, considering that EVs do not emit poisonous gases while driving. The local weight of this sub-criterion is $\tilde{\omega}_{G1l} = 0.3119$. Experts point out that the sub-criterion G5 is the least important, as it evaluates the lower noise generated by EVs (local weight $\tilde{\omega}_{G5l} = 0.079$) and makes sub-criterion G1 more significant (3.95-times).

7.3. Global Weights and Priorities of the Sub-Criteria

According to Formula (19), the local weights of the main criteria and sub-criteria that determine the deployment of EVs in the country assisted in calculating the global weights ω_{ig} and global priorities of all 50 sub-criteria (Table 12). The global weights of the sub-criteria differ. The dominance of the 22 most significant sub-criteria for the global weights is greater than the weight average of 0.02 and is presented in Figure 4.

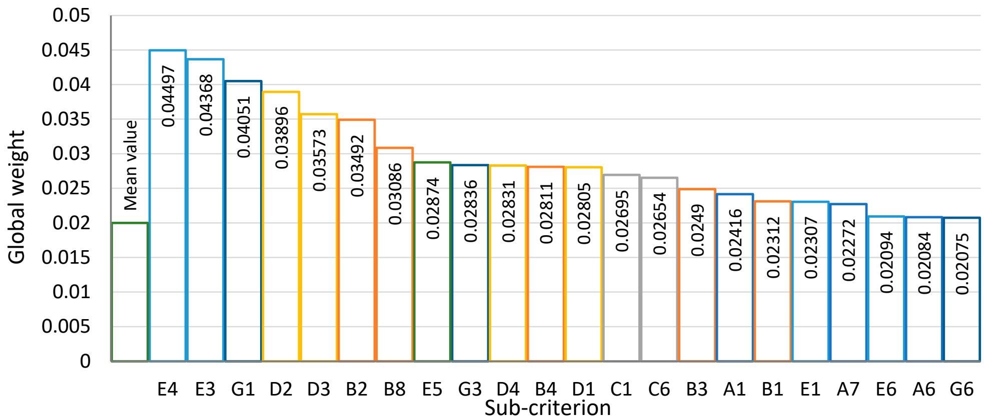

Figure 4. The priority of 22 sub-criteria that are more important than the averaged global weight (0.02) and have the greatest impact on EV deployment in the country.

According to the calculated data, the experts agree that the higher costs of manufacturing and purchasing EVs (E4) and the application of the financial benefits of purchasing EVs (E3) are the most important sub-criteria for EV deployment in Lithuania. Following the above economic sub-criteria and bearing in mind significance, the third position is taken by the environmental sub-criterion considering the fact that, while driving, EVs do not emit poisonous gases (G1).

The fourth and fifth positions are occupied by sub-criteria D2 and D3, evaluating the installation and development of public charging infrastructure. Among the most significant positions, the sixth and seventh are taken by sub-criteria B2 and B8. These are used to evaluate technical and operational parameters, such as the durability of batteries (number of charge–discharge cycles), the long time taken to charge EV batteries (longer than filling a fuel tank), and the imposed Lithuanian ban on charging for an unlimited period of time since 2022.

In order to accelerate EV deployment in the country, decision makers must provide abundant resources to develop the above-discussed sub-criteria, the significance of which is the greatest. Practical actions based on the particular strategy introduced are likely to lead to the best outcome of development.

For future studies, it is planned to investigate the opinions of experts in the road transport sector, determining the significance of factors that have a decisive effect on EV deployment in the country and the positions of natural and legal persons who have purchased EVs or intend to do so. The decisions of individuals to buy EVs determine the total number of EVs in the country; therefore, practical measures must be developed to more effectively encourage people to replace ICE-powered vehicles with EVs.

Table 12. The local and global weights and priority of the criteria for EV deployment.

The Main Criterion and Weight $\overline{Q}_{i,mc}$	Sub-Criterion	Local Weight $\tilde{\omega}_{il}$	Local Priority	The Product $\overline{Q}_{i,mc} * \tilde{\omega}_{il}$	The Product $\overline{Q}_{i,mc} * \tilde{\omega}_{il} * m_{i,mc}$	Global Weight ω_{ig}	Global Priority
A. Studies on and legal acts regulating electric vehicle (EV) deployment $m_{A,mc} = 7$ $\overline{Q}_{A,mc} = 0.1226$	A1	0.1981	1	0.02429	0.17001	0.02416	16
	A2	0.1216	4	0.01491	0.10436	0.01483	31
	A3	0.0899	7	0.01102	0.07715	0.01096	42
	A4	0.1150	6	0.01410	0.09869	0.01402	33
	A5	0.1182	5	0.01449	0.10144	0.01442	32
	A6	0.1709	3	0.02095	0.14667	0.02084	21
	A7	0.1863	2	0.02284	0.15988	0.02272	19
B. Technical and operational parameters for electric vehicles $m_{B,mc} = 8$ $\overline{Q}_{B,mc} = 0.1633$	B1	0.1245	5	0.02033	0.16265	0.02312	17
	B2	0.1881	1	0.03072	0.24573	0.03492	6
	B3	0.1341	4	0.02190	0.17519	0.02490	15
	B4	0.1514	3	0.02472	0.19779	0.02811	11
	B5	0.0667	8	0.01089	0.08714	0.01238	39
	B6	0.0726	7	0.01186	0.09484	0.01348	35
	B7	0.0964	6	0.01574	0.12594	0.01790	24
	B8	0.1662	2	0.02714	0.21712	0.03086	7
C. The action of the initiative subjects for EV deployment $m_{C,mc} = 6$ $\overline{Q}_{C,mc} = 0.1241$	C1	0.2547	1	0.03161	0.18965	0.02695	13
	C2	0.1646	3	0.02043	0.12256	0.01742	26
	C3	0.1192	4	0.01479	0.08876	0.01261	37
	C4	0.1065	5	0.01322	0.07930	0.01127	40
	C5	0.1042	6	0.01293	0.07759	0.01103	41
	C6	0.2508	2	0.03112	0.18675	0.02654	14
D. Development of public EV charging infrastructure $m_{D,mc} = 5$ $\overline{Q}_{D,mc} = 0.2059$	D1	0.1917	4	0.03947	0.19736	0.02805	12
	D2	0.2663	1	0.05483	0.27416	0.03896	4
	D3	0.2442	2	0.05028	0.25140	0.03573	5
	D4	0.1935	3	0.03984	0.19921	0.02831	10
	D5	0.1043	5	0.02148	0.10738	0.01526	29

Table 12. *Cont.*

The Main Criterion and Weight $\overline{Q}_{i,mc}$	Sub-Criterion	Local Weight $\tilde{\omega}_{il}$	Local Priority	The Product $\overline{Q}_{i,mc}*\tilde{\omega}_{il}$	The Product $\overline{Q}_{i,mc}*\tilde{\omega}_{il}*m_{i,mc}$	Global Weight ω_{ig}	Global Priority
E. Economic factors $m_{E,mc} = 10$ $\overline{Q}_{E,mc} = 0.1648$	E1	0.0985	4	0.01623	0.16233	0.02307	18
	E2	0.0634	8	0.01045	0.10448	0.01485	30
	E3	0.1865	2	0.03074	0.30735	0.04368	2
	E4	0.1920	1	0.03164	0.31642	0.04497	1
	E5	0.1227	3	0.02022	0.20221	0.02874	8
	E6	0.0894	5	0.01473	0.14733	0.02094	20
	E7	0.0466	10	0.00768	0.07680	0.01091	43
	E8	0.0585	9	0.00964	0.09641	0.01370	34
	E9	0.0730	6	0.01203	0.12030	0.01710	27
	E10	0.0694	7	0.01144	0.11437	0.01625	28
F. Social factors $m_{F,mc} = 8$ $\overline{Q}_{F,mc} = 0.0670$	F1	0.2401	1	0.01609	0.12870	0.01829	23
	F2	0.1725	2	0.01156	0.09246	0.01314	36
	F3	0.1217	4	0.00815	0.06523	0.00927	46
	F4	0.1227	3	0.00822	0.06577	0.00935	45
	F5	0.0716	8	0.00480	0.03838	0.00545	50
	F6	0.0909	6	0.00609	0.04872	0.00692	48
	F7	0.0724	7	0.00485	0.03881	0.00552	49
	F8	0.1081	5	0.00724	0.05794	0.00823	47
G. Ecological (environmental) factors $m_{G,mc} = 6$ $\overline{Q}_{G,mc} = 0.1523$	G1	0.3119	1	0.04750	0.28501	0.04051	3
	G2	0.0957	5	0.01458	0.08745	0.01243	38
	G3	0.2184	2	0.03326	0.19957	0.02836	9
	G4	0.1352	4	0.02059	0.12354	0.01756	25
	G5	0.0790	6	0.01203	0.07219	0.01026	44
	G6	0.1598	3	0.02434	0.14603	0.02075	22
Total	–	7.0000	–	–	7.03652	1.00000	–

8. Conclusions

Air pollution caused by road transport is effectively reduced by the faster replacement of conventional ICE-powered vehicles with electric vehicles (EVs). In different countries, the EV fleet takes a different proportion of all road vehicles, which has been determined by the different levels of economy, transport development strategy, user habits, promotion methods, suitability of infrastructure, technical and operational parameters for EVs, and environmental requirements. It is consistent to establish the integrated influence of the above-mentioned and other factors on EV deployment in the country with reference to expert knowledge and experience, which allows one to calculate subjective weights and priorities using MCDM methods.

The authors of this paper created an original system of 50 sub-criteria divided in the hierarchical structure that helped in the evaluation of 12 experts to be presented with local and global weights and priorities. To increase the reliability and representativeness of the obtained results, three MCDM methods, including ARTIW-L, ARTIW-N, and AHP, were used in this study. The calculated values of the concordance coefficient and the consistency ratio show that the expert opinions were consistent. The averages of the local weights of the main criteria and sub-criteria calculated employing the introduced methods were accepted as an intermediate result of the problem solution. Finally, the calculated values of global weights and priorities were presented, thus comparing all 50 sub-criteria with each other.

The global weights of the sub-criteria show that economic sub-criteria have the greatest effect on EV deployment in Lithuania, considering the excessive costs of EV manufacturing, unaffordable prices for purchasing these vehicles, and the application of the financial benefits of purchasing EVs (subsidies for EV buyers). The experts interviewed expressed the opinion that customers (owner or driver who chooses their next vehicle according to the type of powertrain) find it important that EVs do not emit toxic gases into the environment while driving (Priority 3). In terms of significance, the fourth and fifth positions are occupied by infrastructure factors, such as the installation and development of DC high-power charging stations and the lack of public electric vehicle charging infrastructure in the five most populous Lithuanian cities and resorts, as well as in the main trans-European road network. EV technical and operational parameters such as the durability of the batteries used and the long charging time of the EV battery, which takes longer than the fuel tank fill time, are placed in the sixth and seventh positions. The eighth is the economic sub-criterion evaluating the difference between the cost of electricity used by EVs and fossil-fuelled vehicles to travel the same distance. In this way, the cost for EVs is lower than for conventional vehicles; however, it tends to increase.

Experts agree that social factors are the least significant for EV deployment in the country: the sub-criteria from F3 to F8 occupy positions from 45 to 50. The belief that reducing environmental pollution is the responsibility of every citizen (F1) and advertising a positive effect of EV deployment on the environment and people's quality of life along with the demonstrations organised by climate activists (F2) take positions 23 and 36, respectively, and are of moderate significance.

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