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Sustainable Mobility Driven Prioritization of New Vehicle Technologies, Based on a New Decision-Aiding Methodology

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Abstract: In an era of environmental and socio-economic crisis, sustainable transport planning is vital as ever, especially given that the transport sector is responsible for the greatest part of total air pollution and greenhouse gas emissions. New vehicle technologies, such as autonomous and electric vehicles, emerge as promising alternatives, creating, however, both opportunities and challenges and raising questions relating to their performance. Can these new vehicle technologies really perform better than conventional ones in terms of sustainable mobility? Which one of them constitutes the optimum solution? How does each alternative perform with regard to different evaluation criteria, such as air pollution or road safety? In order to answer such questions, and to select the optimum solution, a comparison between autonomous, electric, autonomous electric and conventional vehicles is executed, based on a set of social, economic and environmental criteria. For this purpose, a new decision-aiding methodology, allowing for a holistic evaluation of the alternatives through a comprehensive literature review and experts' participation, is applied. It is mainly based on the combined application of two hybrid multi-criteria analysis models, creating a more solid background towards optimum decision-making, thus constituting an important decision support tool for project appraisal and funding within the framework of sustainability in any sector.

Keywords: autonomous vehicles; electric vehicles; sustainable mobility; transport policy; multi-criteria analysis; transport project evaluation; decision-making; transport planning

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1. Introduction

Decision-making within the framework of sustainability has become imperative during the last few years, with air pollution and climate change highlighting even more the need to integrate sustainability objectives into project evaluation and appraisal. As regards greenhouse gas emissions (GHG) from the transport sector in the European Union (EU), which account today for more than one quarter of the EU's total GHG, they have been increasing since 2014, with the transport sector being the only sector failing to meet the reduction goals set in the 2011 White Paper, substantially contributing to climate change [1]. At the same time, it constitutes a significant source of air pollution (particulate matter, NO_x etc.), especially in urban areas, while approximately three quarters of the total annual GHG from transport is generated by road transport [1]. Consequently, sustainable development strategies, especially in Europe, should focus on transportation, with social, environmental and economic criteria having to be taken into account in project evaluation, appraisal and funding. To this end, the EU has launched a set of initiatives, both at institutional and at research level, towards promoting sustainable mobility, with strategies based on new vehicle technologies holding a preponderant place in the agenda [2,3].

However, the demand for a compromise between many and, often, conflicting criteria, along with the complex allocation of responsibilities and conflicting interests of stakeholders, turns decision-making for sustainable mobility projects into a complicated and multi-factor problem to solve, especially for urban areas, where transport problems are more intense, and in times of socio-economic and environmental crisis. The application of a decision-making methodology that allows for a holistic evaluation of project alternatives within the framework of sustainable mobility is therefore of high importance.

According to a relevant literature review [4], the most commonly applied transport project evaluation methods (and, in this sense, decision-aiding methods) are cost-benefit analysis (CBA) and multi-criteria analysis (MCA) methods, with the latter making remarkable headway during the last few years, while cost-effectiveness analysis (CEA) is also applied in many cases [5]. However, methods such as CBA or CEA are often negatively criticized, as they impose the conversion of all the parameters into monetary units, something difficult or even impossible in many cases, often resulting in the omission or incorrect inclusion of certain parameters, while they usually fail to include stakeholders' preferences in the process [6,7]. Apart from technical issues, ethical issues are raised as well, concerning the conversion of certain parameters into monetary units (such as human life costing) [8]. As a result, decision-makers often end up selecting solutions which are either ineffective or inefficient. MCA methods allow for the inclusion of qualitative and quantitative criteria, and tangible and intangible parameters, in the analysis, without imposing their conversion into monetary units, while stakeholders' preferences and experts' opinions can be integrated into the process [4,8]. Moreover, MCA methods allow for the more efficient management of large amounts of data relating to decision-making, especially in the context of sustainable mobility, which requires the satisfaction—at the same time—of social, economic and environmental criteria [4,5,8–10]. For these reasons, MCA methods have been gaining more and more ground in the literature, for the evaluation and selection of transport projects, over the last few years, and even more the combination of MCA methods [10–14]. However, the risk of subjectivity when attributing weights to the criteria or when evaluating the alternatives is mostly mentioned as the main drawback of MCA methods, for the "remedy" of which a group of experts or stakeholders usually participates in such procedures [10]. There is a large number of MCA methods, but, concerning the transport sector, AHP (Analytic Hierarchy Process) [15], TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [16], VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) [17], ELECTRE (Élimination et Choix Traduisant la Réalité) "family" [18] and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) "family" [19] are the most applied ones [10].

Apart from the advantages of MCA compared to a CBA or a CEA, already mentioned, the combined application of two hybrid MCA models, with the introduction of an additional condition and other methodological steps, as presented in this research work, allows for the exploitation of the strengths of each method and leads to the extraction of more reliable and valid results, in comparison with the application of each method or model separately. A more solid background for optimum decision-making is therefore constructed and the possibility of selecting an improper or insufficient solution is minimized, especially within the demanding framework of sustainable mobility, while the participation of a group of experts contributes to minimizing subjectivity.

The proposed methodology can serve as an important tool for analysts and decision-makers charged with project evaluation, appraisal and funding (Municipalities, Ministries, European Union, etc.), in various sustainability sectors, and especially in the key sector of transportation. The methodology can substantially contribute to proper policy formulation at local, regional, national, European and international levels, as it allows for the identification of those alternatives that shall be promoted and funded, with a view to minimizing the cost and maximizing the benefit at social, environmental and economic levels. The value of such a methodology is even higher in times of economic "stringency" and environmental crisis, when the management of resources has to be realized with even more prudence and the need for a sound decision-making methodology is as imperative as ever.

As already mentioned, new vehicle technologies, such as autonomous and electric vehicles, hold a preponderant place in the EU sustainable mobility agenda. These new technologies arise as very promising alternatives towards sustainable mobility and are expected to replace conventional vehicles in road networks within the next few decades, after their "co-existence" for a certain period. To date, there are no analyses concerning the evaluation and optimum selection among autonomous, electric, autonomous electric and conventional vehicles, especially not in the context of sustainable mobility, except for a limited number of analyses concerning the comparison between electric and conventional vehicles or among different types of electric vehicles, as described in Section 2.3. Attempting to fill this gap, a preliminary (mainly due to the low maturity level of autonomous vehicles) evaluation of these new vehicle technologies, along with conventional vehicles, is conducted in this study, applying the proposed decision-aiding methodology, with the participation of a group of renowned experts. The evaluation of these new vehicle technologies is based on an initial list of criteria identified through a comprehensive literature review, taking into account their expected impacts at social, economic and environmental levels, especially in urban areas. It is investigated whether these new technologies can perform better than conventional ones in terms of sustainable mobility, which one of them constitutes the optimum solution and how each alternative performs with regard to each evaluation criterion.

This research work is structured as follows. Autonomous and electric vehicle characteristics and expected impacts at economic, environmental and social levels, based on a comprehensive literature review, any existing evaluation studies, as well as the proposed decision-aiding methodology, are presented in Section 2. In Section 3, the methodology is applied for the evaluation and optimum selection of new vehicle technologies within the framework of sustainable mobility, while discussion of the main results and conclusions can be found in Section 4.

2. Materials and Methods

2.1. Autonomous and Electric Vehicle Definitions

The terms "automated vehicles" and "autonomous vehicles" are often used without distinction in the literature. However, automated vehicles are the ones disposing of one or more automated functions, while—according to [20]—there are 6 mutually exclusive automation levels, also adopted by the National Highway Traffic Safety Administration (USA) [20,21]. Autonomous vehicles, consistent with the etymology of the word "autonomous", the origin of which is Greek (*αυτόνομος*) and means "independent, being able to function without depending on anything/ anybody else" [22], should in fact be considered only the ones that are able to truly move on their own (without needing to be controlled by a human driver), in any weather and traffic conditions, thus only vehicles of automation level 5, according to [20]. Vehicles of automation level 4 (autonomous in certain traffic and weather conditions) and level 3 (autonomous in certain traffic and weather conditions, with the driver having to be ready to take back control after relevant warning signals), as well as vehicles of automation level 2, are called "semi-autonomous" in [23], while it is noted that vehicles of automation levels 3 to 5 are referred to as "highly automated vehicles" in [24]. It should also be noted that autonomous vehicles (of automation level 5) shall, obviously, be connected (Connected vehicles are vehicles able to communicate—through appropriate equipment—with road infrastructure, other vehicles, other road network users and the "Cloud", within the framework of road safety, comfort and driving efficiency improvement [25,26].) as well, in order to perform all the necessary functions demanding the communication with the infrastructure or other road network users [27]. Given the confusion of the terms automated and autonomous, regularly found in the literature, with the terms "autonomous" and "automated" being used without distinction, it is clarified that, in the present work, the term "autonomous vehicles" refers to vehicles of automation level 5, which are also connected.

As regards electric vehicles, according to Directive 2014/94/EE [28], the term "electric vehicle" refers to "*a motor vehicle equipped with a powertrain containing at least one non-peripheral electric machine as energy converter with an electric rechargeable energy storage system, which can be recharged externally*". The energy required for its movement may stem from conventional (e.g., carbon or gas) or from renewable energy sources (e.g., sun, wind, water, biomass, geothermy) [29].

Electric vehicles can be classified into five main categories: Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicles (PHEV), Range Extender Electric Vehicles (REEV) and Fuel Cell Electric Vehicles (FCEV) [30,31]. Among these types, BEV ("participating" in the analysis of Section 3) are zero-emission vehicles, with remarkably high (even more than 80%) efficiency [31].

2.2. Electric and Autonomous Vehicle Characteristics and Expected Impacts at Economic, Environmental and Social Level

BEV are characterized by high levels of energy efficiency, significantly less transport waste compared to fossil fuel vehicles and zero pollutant emissions when moving, with the environmental footprint being further reduced in case renewable resources are used for the production of the energy required for their power [30–35]. Electric vehicles can also contribute to noise pollution reduction, as they are "silent" when moving, despite the fact that this makes certain drivers feel uncomfortable, generating road safety issues relating to vulnerable users of road networks (e.g., pedestrians or cyclists), who might not perceive them early enough to protect themselves [36]. Furthermore, BEV are characterized by relatively low battery range, compared to internal combustion machine vehicles (although significant progress has been made), while charging infrastructure is not yet sufficient in most countries, constituting an important discouraging factor towards electric vehicle acquisition, in combination with the fact that the charging time of an electric vehicle is longer than the refueling time of a conventional one [36,37]. Apart from these, battery life is relatively limited (usually between 3 and 5 years), although certain companies provide their customers with a guarantee of even up to 8 years for certain models [36]. It should be noted, though, that concerns relating to electric vehicles' adoption as the "absolute" solution within the framework of sustainable mobility have been expressed, due to externalities mainly related to battery material mining, such as lithium, cobalt, manganese and nickel, which may lead to a potentially high environmental footprint [38]. It is therefore important to understand that such vehicle technologies are not a "panacea" to all sustainability problems, regardless of the battery production, recycling or disposal policies that are adopted, for example. However, it is claimed that policies in the context of the circular economy can be truly efficient towards minimizing the negative environmental impacts related to these technologies [39,40], and that such policies will have been adopted by the time these new technologies will massively enter road networks, highly contributing to their better performance compared to conventional ones in terms of environmental footprint [32].

Concerning the acquisition cost of an electric car, it is higher than the cost of its conventional counterpart; however, it is counterbalanced by the lower operation and maintenance cost [29,35,41]. It should be noted that a BEV consists of fewer parts compared to a conventional one, while the most expensive part of a BEV is the battery, the cost of which, however, decreases over the years, both due to improvement of efficiency issues and due to economies of scale [33]. Finally, according to [42], the operation and maintenance cost of electric vehicles further decreases by 14–26% annually (depending on whether the car is a BEV or PHEV, respectively).

Concerning autonomous vehicles, the expected impacts are not yet clear, as their maturity level is low. Due to this low maturity level, relevant modeling is difficult, with the authors of relevant work stressing that significant assumptions are made, that any results must be carefully interpreted and that a more complete and accurate future simulation is necessary, so that sufficiently reliable results are derived [43–46].

Autonomous vehicles are expected to lead to either an increase or decrease in the total passenger-km traveled, depending on factors such as the ability of the elderly or people with impairments to use a car on their own, users' opportunity to exploit travel time in a more efficient way, discharge from driving, whether the vehicles will be shared or pooled, etc. [47–51].

The impact on traffic congestion may be either positive or negative, depending on factors such as the opportunity to better exploit road networks (e.g., in case of platoons), the expected road safety improvement (given that an accident can cause delays), the increase in traveled passenger-km, etc. [52–54]. In general, the higher the automation and connectivity level, as well as the market penetration rate of CAV (connected and automated vehicles), the more possible it is to have positive impacts on traffic flow, with vehicle heterogeneity being the most crucial factor for problems relating to traffic flow at entrance and exit points of motorways [47,49,55,56].

The expected impacts on road safety are not clear either. On the one hand, autonomous vehicles may lead to a reduction in the number of road accidents (from 40% to 90%), given that more than 90% of them are due to human error (such as alcohol, exhaustion, drugs, etc.) [47,49,57,58]. On the other hand, dangers relating to new technologies, especially during the transitional period, such as hardware or software breakdown, hacking, attempt of drivers of conventional vehicles to enter platoons, etc., should be taken into account [27,49,58].

As regards time value, it is expected that autonomous vehicles will have a positive impact on it, as passengers will be discharged from vehicle control, being able to "exploit" travel time in an efficient way (e.g., working, sleeping, entertaining, etc.) [49,52]. Moreover, delays due to accidents are expected to decrease [49,57,59].

With regard to land use, the impacts of autonomous vehicles are ambiguous too [60]. According to one scenario, the opportunity to better exploit travel time, given the discharge from driving, may lead to a sort of "de-urbanization", with suburbs and rural areas being developed (as traveling could be easier), but, according to another scenario, city centers could be further developed and more attractive, as the discharge from searching for a parking place could lead to a reduction in parking places (which may be up to 31% in an urban area) in city centers, given that autonomous vehicles could leave their passengers at their destination and then go to car parks around the center, also offering the opportunity for the "recovery" and regeneration of public space (this "free" parking space could be "transformed" into playgrounds, parks, bicycle lanes, green areas, etc.) [27,49,60–62].

Concerning natural resource consumption, air pollution and the greenhouse effect, the consequences may be either positive or negative, depending on factors such as the impact that autonomous vehicles will have on the total number of traveled passenger-km, on whether autonomous vehicles will at the same time be electric (especially in the case of BEV with renewable energy sources) and shared or pooled, on vehicle energy efficiency, on road safety improvement (lighter vehicles, thus reduction in fuel consumption and less transport waste), on whether the demand for parking places in cities will decrease (given that searching for a parking place causes additional pollutant emissions), etc. [27,49,52,55,61,63–65].

Concerning the acquisition, operation and maintenance costs of autonomous vehicles, these are estimated at high levels, especially during the first years of their circulation, with a reduction being expected within 10 to 30 years after their entrance into road networks [52]. There are few attempts to estimate this cost in the relevant literature, while, as there are no reliable data yet, due to the low maturity level of these technologies, the researchers dealing with such issues stress that the results of their research should be interpreted with caution, as, in the future, data are likely to change [47,63,65,66].

It is also worth mentioning that, according to relevant surveys, the most common reasons for autonomous vehicles' user acceptance is the discharge from searching for a parking place and from the parking process itself, as well as the advantage of exploiting travel time in a creative way [67,68]. However, autonomous vehicles might cause a sense of low comfort and safety to potential users, mainly due to the fear of conceding the control of the car to a "robot" or due to perceived dangers relating to hacking or breakdown, for any reason, of electronic systems [68,69], with such fears being mitigated, to an extent, in case of circulation of autonomous vehicles in separate lanes, instead of mixed flow with conventional or lower automation level vehicles [68].

In terms of social equity, autonomous vehicles could have positive impacts, as the elderly or people with impairments will be able to use a car on their own, although the high cost might make them forbidden for certain people [49,52]. As for privacy issues, questions are raised concerning personal data and protection of privacy in the case of autonomous vehicle use, especially in the case of shared autonomous vehicles, e.g., due to GPS, CCTV cameras, etc. [52], while in [53,56,70], concerns relating to "behavioral adaptation" problems or even of cognitive skills' degradation over time are also expressed.

2.3. Electric and Autonomous Vehicle Evaluation

There are certain articles evaluating electric vehicles by means of CBA, CEA or similar methods [42,71–75]. However, in such analyses, important evaluation parameters are often neglected because their quantification is difficult or even impossible. Aiming at filling this gap, an analysis was carried out in [76], albeit with simplifying assumptions (as stated by the author), aiming at quantifying the benefits stemming from BEV, in terms of economic development, national safety, health impacts, maintenance, fuel savings and environmental CO_2, which are usually neglected in CBA, because their translation into monetary units is either difficult or impossible. According to the results of the cost analysis and CEA carried out in [73], relating to HEV and BEV, despite the omission of parameters that are difficult to quantify, HEV and BEV seem to be preferable to conventional ones, with BEV outweighing HEV too. A CBA conducted in [75] comparing PHEV and conventional vehicles revealed the superiority of PHEV, but the parameters taken into consideration were only related to the benefit and cost of vehicle acquisition, energy and fuel consumption. In [42], a CBA on BEV and HEV reveals that it is expected that their cost will be gradually reduced over the years, while a reduction in CO_2 emissions and generally in environmental emissions (even in the case of conventional energy sources) is also expected, even though the reduction in NO_x and particulate matter is not expected to be remarkable.

MCA for the evaluation of electric vehicles has been carried out, albeit to a small extent, and to an even smaller extent concerning private electric cars [35,77], while there is not yet a "unanimously accepted" set of criteria, with the requirement of defining a different set of criteria in every case [35]. Although there is a certain number of analyses relating to alternative fuel technologies, including electric energy [78–80], there are only a few analyses including social and economic components. Aiming at filling this gap, life-cycle sustainability assessment was combined with multi-objective decision-making (type of MCA) in [77], for the optimum selection of passenger transport in the U.S.A., with 7 different vehicle types being evaluated: combustion engine, HEV, PHEV of 16, 32, 48 and 64 km range and BEV (the energy required for electric vehicles comes either from conventional energy sources or from the sun), but socio-economic parameters, such as social equity, safety, public health, etc., are not taken into account. In [35], a Hierarchical Hesitant Fuzzy Linguistic Model (a type of MCA) is applied for the selection of alternative fuel vehicles for freight transport (a fleet of a healthcare service provider in the U.S.A. is selected as a case study), with BEV emerging as the optimum solution among different vehicle types (gasoline, diesel, biodiesel, electricity, ethanol, hydrogen, natural gas, propane).

Concerning autonomous vehicles, there is only a limited number of articles dealing with the evaluation of vehicles of automation levels 4 and 5, especially in urban areas, based on a CBA or relevant methods or MCA [47,66,81]. This is obviously due to the low maturity level of these new technologies and to the subsequent high degree of uncertainty concerning the parameters that should be considered in such analyses, with the authors expressing concerns relating to the reliability of the derived results, stressing that it is too early to derive sufficiently reliable results.

In [47], the annual expected economic benefits due to the advent of autonomous vehicles in the U.S.A. are estimated, in terms of safety, traffic congestion and parking. In [81], TOPSIS is applied for the evaluation of three new vehicle technologies (automation level 4, communication system between vehicles, communication system between vehicles and infrastructure), in the form of 9 relevant scenarios. The evaluation is based on five criteria (safety, cost, availability, compatibility, fuel efficiency), defined and weighted by the authors. In [66], a cost-based analysis of vehicles of automation level 5 is realized, including only financial components (acquisition vehicle cost, operation and maintenance vehicle cost), for three main vehicle types (public transport, pooled or individual taxis and private cars).

2.4. Proposed Methodology and Engaged Methods

2.4.1. Brief Overview of AHP Hierarchy Structure and Pair-Wise Comparisons

The AHP [15] decomposes a complex decision-making problem into a set of hierarchy levels, including the overall goal at the highest level, the criteria at the second one and the alternatives at the lowest level. Then, the criteria are pair-wise compared concerning their contribution to the achievement of the overall goal, based on a 1–9 scale. The alternatives are also pair-wise compared with regard to each criterion in terms of preference, so that a pair-wise comparison matrix, such as the one shown in relation (1), is derived in every case [82], where n is the number of elements of the same hierarchy level. The entry $\alpha_{ij} = w_i/w_j$ represents the relative importance of the element i over the element j, when compared in terms of the elements of the upper level, while w_i and w_j are the weight coefficients of the elements i and j, respectively [82]. Obviously, $\alpha_{ij} = 1/\alpha_{ji}$ and $\alpha_{ii} = w_i/w_i = 1$.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

The normalization of the pair-wise comparison matrix follows, by dividing each element by the sum of the elements of the same column.

The following equation links the matrix A and the priority vector $W = (w_1, w_2, \dots, w_n)^T$ for each hierarchy level, where λ_{max} is the principal eigenvalue of matrix A:

$$(A - \lambda_{max}) \times W = 0 \quad (2)$$

For the calculation of the priority vector, the mean value of the elements of each row of the normalized matrix is calculated, but due to inconsistencies, which have to be taken into account, the consistency ratio (*CR*) is as follows:

$$CR = CI/RI, \quad (3)$$

where *RI* is the random consistency index, given in Table 1 for n compared elements, while *CI* is the consistency index:

$$CI = \frac{\lambda_{max} - n}{n - 1}. \quad (4)$$

The consistency control is satisfied when $CR \leq 0.10$; otherwise, the problem has to be re-examined and the judgments have to be reconsidered.

Table 1. RI values for n pair-wise compared elements [15].

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.4.2. Brief Overview of TOPSIS

The optimum alternative in the context of TOPSIS [16] application is defined as the one characterized by the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (the most common way to calculate both distances is the Euclidian distance approach). A decision matrix, such as that shown in relation (5), for n criteria and m alternatives, where the element x_{ij} represents the performance of the alternative A_i in terms of the criterion C_j, where i = 1, 2, ... , m and j = 1,2, ... , n, is formulated.

$$D = \begin{matrix} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} \begin{matrix} C_1 & C_2 & \dots & C_n \\ \left[\begin{matrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{matrix} \right] \end{matrix} \quad (5)$$

The next step includes the normalization of the above decision matrix with any normalization technique; with a vector normalization technique, for example, the elements r_{ij} of it can be calculated as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (6)$$

Subsequently, the weighted normalized matrix, with the v_{ij} elements, is calculated:

$$v_{ij} = w_j \cdot r_{\mathrm{ij}}, \quad (7)$$

where w_j the weight of the criterion C_j *(where j = 1,2, ... , n)* and $\Sigma wj = 1$.

The ideal (A^+) and negative-ideal (A^-) solutions are then calculated:

$$A^+ = \{(max_i v_{ij} \mid j \in J), min_i v_{ij} \mid j \in J') \mid i = 1,2, \dots ,m\} = \{ v_1{}^+, v_2{}^+, \dots , v_j{}^+, \dots , v_n{}^+\} \quad (8)$$

$$A^- = \{(min_i v_{ij} \mid j \in J), max_i v_{ij} \mid j \in J') \mid i = 1,2, \dots ,m\} = \{v_1{}^-, v_2{}^-, \dots , v_j{}^-, \dots , v_n{}^-\}, \quad (9)$$

where *J = {j = 1,2, ... n* and *j* refers to benefit criteria} and *J′ = {j = 1,2, ... n* and *j* refers to cost criteria}.

The so-called "separation measure" (distance of each alternative from the ideal and the negative-ideal solution) is then calculated, applying the "Euclidian distance method".

Euclidian distance of the alternative A_i from the ideal solution ($S_i{}^+$):

$$S_i{}^+ \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^+\right)^2}, \text{ where } i = 1, 2, \dots, m. \quad (10)$$

Euclidian distance of the alternative A_i from the negative-ideal solution ($S_i{}^-$):

$$S_i{}^- = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^-\right)^2}, \text{ where } i = 1, 2, \dots, m. \quad (11)$$

The final step consists of the calculation of the relative closeness $c_i{}^+$ to the ideal solution:

$$c_i{}^+ = \frac{S_i^-}{\left(S_i^+ + S_i^-\right)}, \text{ where } 0 \le c_i{}^+ \le 1 \text{ for } i = 1, 2, \dots, m \ (c_i{}^+ = 1 \text{ if } A_i = A^+ \text{ and } c_i{}^+ = 0 \text{ if } A_i = A^-) \quad (12)$$

The alternatives are ranked on the basis of $c_i{}^+$ values (maximum $c_i{}^+$ value → best alternative).

2.4.3. Brief Overview of VIKOR

The optimum compromise solution among a set of alternatives in the case of VIKOR [17] application is a feasible solution which is the closest to the ideal, based on mutual concessions between the conflicting criteria of the decision problem. After having constructed the decision matrix, such as the one shown in relation (5), for n criteria and m alternatives, the best (f_j^*) and the worst (f_j^-) performance values for each criterion function are calculated.

For benefit functions (the maximum value is better):

$$f^*{}_j = max_i(x_{ij}) \text{ and } f_j = min_i(x_{ij}), \quad (13)$$

and for cost functions (the minimum value is better):

$$f^*_j = min_i(x_{ij}) \text{ and } f_j = max_i(x_{ij}), \tag{14}$$

where i = 1, 2, ... , m and j = 1, 2, ... , n.

The group utility (S_i) and individual regret (R_i) values for each alternative A_i *(i = 1, 2, ... , m)* are then calculated:

$$S_i = \sum_{j=1}^{n} (f_j^* - x_{ij} / (f_j^* - f_j^-) \tag{15}$$

$$R_i = max_j \left[w_j \cdot \left(\left(f_j^* - x_{ij} / \left(f_j^* - f_j^- \right) \right] \right., \tag{16}$$

where w_j *(j = 1, 2, ... , n)* are the criteria weights.

The calculation of Q_i values for each alternative A_i *(i = 1, 2, ... , m)* follows (for v = 0.5):

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + (1 - v) \cdot \frac{R_i - R^*}{R^- - R^*}, \tag{17}$$

where

$$S^* = min_j S_i,\ S^- = max_j S_i,\ R^* = min_j R_i \text{ and } R^- = max_j R_i. \tag{18}$$

Finally, the alternatives are ranked on the basis of S_i, R_i and Q_i values of each alternative (minimum value → best alternative and maximum value → worst alternative).

The optimum solution $A^{(1)}$ is the one with the minimum Q_i, provided that the following two conditions are both satisfied:

(i) Acceptable advantage: $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$ (where $A^{(2)}$ the second in rank by Q_i alternative and $DQ = 1/(m-1)$, where m the number of alternatives).
(ii) Acceptable stability: the alternative $A^{(1)}$ should also be the first ranked by S_i and R_i.

In the event that one of the aforementioned conditions is not satisfied, it is considered that the optimum alternative is not only one, so a set of compromise solutions is proposed, consisting of alternatives $A^{(1)}$ and $A^{(2)}$, if condition (ii) is not satisfied, or of alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$, if condition (i) is not satisfied, where $A^{(M)}$ is the worst alternative in rank by Q_i (the alternative with the maximum Q_i), for which $Q(A^{(M)}) - Q(A^{(1)}) < DQ$.

2.4.4. Proposed Methodology

There is a large number of MCA methods, and there is no right or wrong method, but, as already mentioned in the Introduction, AHP, TOPSIS and VIKOR are the most applied ones in the transport sector and are selected as "components" of the proposed methodology. TOPSIS has the fewest rank reversal problems compared to other MCA methods, but weight elicitation and consistency control are allegedly its major drawbacks [83], while the in-depth comprehension of a complex decision problem is relatively difficult, since the decomposition of the problem into its elements under the form of a hierarchy structure (as in the AHP application case) is not provided. VIKOR outweighs the AHP in imposing that the two conditions of "acceptable advantage" and of "acceptable stability" are satisfied, so that the optimum solution has to be optimum both in terms of (maximum) group utility and in terms of (minimum) individual regret [17], while the difference between two successively ranking alternatives has to be discrete enough, so that one can be characterized as definitely better than the other; otherwise, the same ranking position is occupied by more than one alternative. However, as in the TOPSIS case, the weight elicitation, the consistency control and the in-depth comprehension of the problem are not possible without the combination with the AHP. AHP makes the problem more understandable, by decomposing it into its components, clearly reflecting the importance of each element; it offers the opportunity for group decision-making, by calculating the geometric mean of individual pair-wise comparisons, and it allows for the consistency control of pair-wise comparison matrices [84]. For these reasons, AHP is used to derive the criteria weights, as well as the performance of each alternative in terms of each criterion, and to check the consistency of the pair-wise comparison matrices, and TOPSIS and VIKOR are used to derive the overall ranking of the alternatives. The logic diagram of the proposed methodology is shown in Figure 1.

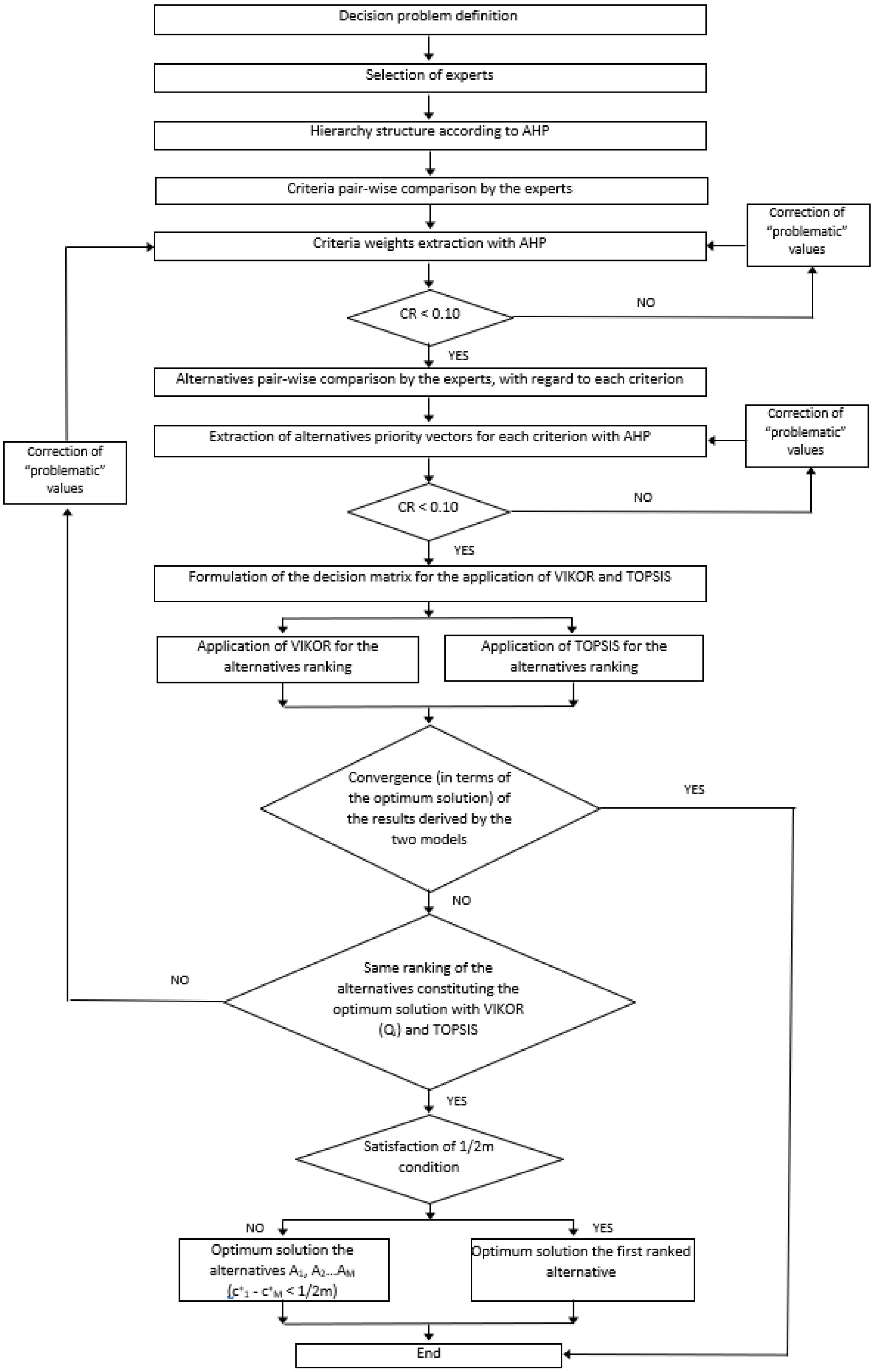

Figure 1. Logic diagram of the proposed methodology.

After having defined the decision problem in its first form (overall goal, "candidate" alternatives, etc.), the appropriate experts are chosen, on the basis of expertise level (relevant studies, professional and research experience, etc.). A number of 8–15 experts is recommended for such procedures [14,85,86]. It is also recommended that the pair-wise comparisons are executed anonymously (only the analyst knows what the answers of each one are), so that the equal treatment of all is ensured, while they are free to express their opinion without being influenced by others or afraid to be "exposed" [14,87,88].

It should be stressed that the role of the experts is crucial for this methodology. Apart from the demand for a high expertise level, their number is also important, as it must be large enough to minimize subjectivity but also reasonable for such a procedure, where the interaction with the analyst and other participants (direct or indirect) is necessary. A high level of expertise is required, so that they can properly respond to their demanding tasks. Apart from defining the final lists of the alternatives and the criteria to "participate" in the analysis, based on the initial lists formed by the analyst through the comprehensive literature review, and taking into account any particularities and special needs of the decision problem, they are also asked to execute pair-wise comparisons, a very demanding task, analogous to the difficulty degree of the decision problem. They are, in fact, asked to compare the criteria and the alternatives "merging" stakeholders' preferences in the optimum way. For this reason, a high level of knowledge, experience and expertise is required, especially concerning the alternatives' evaluation, as they must be able to take into account all the different parameters relating to the decision problem (based on literature data, public acceptance surveys, etc.). As a consequence, the prudent selection of the experts is a highly crucial step for the proper implementation of the proposed methodology.

Based on the literature review, the initial lists of the alternatives and of the criteria are formed by the analyst. The number of compared elements must be large enough to ensure the "reflection" of the most important aspects in the analysis, but also reasonable, so that the pair-wise comparison between them is feasible, not causing confusion to the participants [14], as the human mind is considered to be capable of comparing up to 7 $\pm$ 2 elements in pairs [82]. The selection of the most appropriate alternatives and of the most important criteria can be realized with different techniques, such as Delphi, meetings with the experts or modified Delphi (as applied in Section 3.5 of the present work for the final criteria list). The decision problem is then "decomposed" into its elements, with the hierarchy (overall goal, alternatives, criteria) structured according to AHP (Section 2.4.1). It should be noted that, depending on the nature of the decision problem, the analyst may decide that, in the alternatives and criteria definition stage, stakeholders may directly participate too (e.g., through relevant fora, meetings or public discussion).

The pair-wise comparison questionnaires' distribution to the experts follows. The aggregation of the experts' judgments is realized through the application of the "aggregation of individual judgments method", according to which the average score attributed to each criterion (or alternative in the next step) by the experts is calculated [14,89]. The use of the geometric mean (for a set of n numbers $x_1, x_2, \ldots, x_n$, it equals $\sqrt[n]{x_1 \times x_2 \ldots \times x_n}$) is recommended instead of the arithmetic mean, as it is considered more stable, given that it is less influenced by eventual extreme values, while it ensures the satisfaction of the "reciprocal property" [90,91].

AHP (as described in Section 2.4.1), having as input the corresponding geometric mean values, is applied for the extraction of the criteria weights (priority vectors), with the consistency control ($CR < 0.10$) being executed as well. In the event that $CR > 0.10$, the "problematic" values (generating inconsistencies and discordance) are identified and, if necessary, after communication with the experts, are changed, and the analysis is carried out again, as shown in Figure 1. It should be noted, though, that the reconsideration of "problematic" values is recommended even if $CR < 0.10$, within the framework of data optimization, maximum consensus and consistency of answers. In the case of $CR < 0.10$, the analyst proceeds with the extraction of priority vectors of the alternatives in relation to each criterion, as shown in Figure 1, in the same way. The next step includes the decision matrix formulation for the application of VIKOR and TOPSIS, based on the calculated priority vectors, as shown in Figure 1, so that the overall ranking of the alternatives is derived in every case.

In the case of convergence concerning the solution derived by each model, the process ends, as shown in Figure 1. Otherwise, it is checked whether the alternatives' ranking according to VIKOR (in terms of Q_i) coincides with that of TOPSIS. If not, a further correction of "problematic" values is realized with the process being repeated from the step shown in Figure 1 (in fact, having carefully followed the previous steps, it is unlikely that this step will be needed). If the ranking is the same (in fact, in case the condition of acceptable stability or the one of acceptable advantage is not satisfied in AHP-VIKOR application, leading to the "co-existence" of more than one alternatives at the first rank), the optimum solution is the one that is also first in ranking according to the AHP-TOPSIS model, provided that an additional condition is satisfied in the context of AHP-TOPSIS application, requiring that the solution ranked first prevails over the others by 1/2m (c_i^+ value of relation (12)), where m is the number of the alternatives, as shown in Figure 1. In case the aforementioned condition is not met, the optimum solution consists in the first two (or more) ranking alternatives (until the condition of 1/2m is satisfied). The introduction of the *1/2m* condition stems from the requirement of clear superiority of the optimum solution compared to the remaining ones, but at the same time not with extreme "strictness", given the requirement of results' convergence between the two models.

Apart from the advantages of MCA compared to a CBA or a CEA, as already mentioned in the Introduction section, the combined application of the two hybrid MCA models, as presented in this research work, allows for the exploitation of the strengths of each method and leads to the extraction of more reliable and valid results, compared to the application of each method or model separately. A more solid background for optimum decision-making is therefore constructed and the possibility of selecting an improper or insufficient solution is minimized. The opinion of a group of experts can be integrated into the analysis, towards minimizing subjectivity, while the analyst is provided with better data and results "oversight". At the same time, the analyst can easily identify the experts' answers "generating" inconsistency, and, if necessary, ask them to reconsider their answers and re-conduct the analysis. Finally, the in-depth comprehension of the problem and the related parameters is ensured. Furthermore, the methods "engaged" in the process are easy to understand and to apply, while there is no requirement for software acquisition, as the analyses can be easily executed in Microsoft Excel.

3. Application of the Proposed Methodology for the Optimum Selection of New Vehicle Technologies within the Framework of Sustainable Mobility

3.1. Case Study Description

Following the steps of Section 2.4.4, the proposed methodology is applied for the evaluation and optimum selection of new vehicle technologies, integrating sustainable mobility principles. Autonomous, electric, autonomous electric and conventional vehicles are compared in terms of a set of social, environmental and economic criteria. As already mentioned, the methodology is applied for low maturity level technologies, based on certain assumptions, integrating the expected impacts at social, environmental and economic level.

3.2. Terminology and Assumptions

It is assumed that autonomous (automation level 5 and connected, as defined in Section 2.1) vehicles (either electric or with fossil fuels) will circulate in separate lanes and not in mixed flow with conventional ones, and that the energy required for BEV (referred as electric vehicles) power mainly comes from conventional sources, while fossil fuel vehicles of automation level 0 to 1 (based on SAE International 2018 classification [20]) are referred as conventional. Vehicles of intermediate automation levels are not included in the present analysis, but may constitute an evaluation subject in future work. It should also be noted that the evaluation is conducted for private use passenger cars, while the area under study is considered to be a typical large urban area of a developed country.

3.3. Decision Problem Definition

Autonomous, electric, autonomous electric and conventional vehicles are evaluated and prioritized within the framework of sustainable urban mobility. Given that sustainable urban mobility refers to the satisfaction of mobility needs at the least possible economic, social and environmental cost, without compromising this ability for future generations [9,92], a set of social, environmental and economic criteria is identified, for the alternatives' evaluation.

3.4. Selection of Experts

Twelve renowned experts in the fields of urban and transport planning, as well as of autonomous and electric vehicles, were selected for the definition and pair-wise comparison of the criteria and the alternatives. As already mentioned in Section 2.4.4, the selection of experts is crucial for this methodology, while a number of 8–15 experts is recommended for such procedures [14,85,86]. Professors, researchers and private sector professionals were selected (Berkeley University of California, Aristotle University of Thessaloniki, National Technical University of Athens, University of Crete, University of Thessaly, Centre for Research and Technology Hellas, transport planning agency and automotive industry). The selection criteria were the relevance of their studies to the evaluation subject (all of them MSc and the vast majority of them—all the professors and the researchers—PhD), their years of experience (at least 15), as well as their active engagement with these new technologies, either at professional or at research level, during at least the last 5 years (publications, research projects, etc.).

3.5. Hierarchy Structure (Goal, Alternatives, Criteria)

The overall goal is to meet the principles of sustainable urban mobility, through the optimum compromise between social, environmental and economic criteria, by selecting the best-performing alternative (autonomous, electric, autonomous electric or conventional vehicles). In order to select the most appropriate alternatives and the most important criteria to form the final lists, as mentioned in Section 2.4.4, meetings with experts and a modified Delphi were realized, as described below.

The alternatives to be evaluated were defined through a literature review by the analyst and meeting with experts, and they are the following 4:

- Conventional vehicles (fossil fuels, automation level 0–1)—C.V.;
- Autonomous vehicles (fossil fuels, automation level 5, connected)—A.V.;
- Electric vehicles (BEV, automation level 0–1)—E.V.;
- Autonomous electric vehicles (BEV, automation level 5, connected)—A.E.V.

Based on the comprehensive literature review (Sections 2.2 and 2.3) relating to the expected impacts of autonomous and electric vehicles in terms of economy, society and environment, as well as to any former evaluation attempts of these new technologies, an initial criteria list was formed by the analyst. The list was then delivered to the experts, asking them to select the 8 most important ones (in their opinion), as well as to add any criterion which could be among the 8 most important ones, according to them, but may probably not have been included in the list for the evaluation of the 4 alternatives. The 8 criteria (based on the "7 ± 2 principle" referred to in Section 2.4.4) selected by at least 70% of the participants (based on the "consensus threshold" between 50 and 97% usually defined in traditional Delphi applications [93]) would constitute the final list for the alternatives' evaluation (modified Delphi). The process was completed at once, with the following 8 criteria being selected:

- Acquisition, operation and maintenance vehicle cost—V.C.;
- Air pollutants and greenhouse gas emissions (particulate matter, NO_x, CO_2, etc.)—P.R.;

- Social equity (accessibility improvement, potential to acquire autonomous vehicles, etc.)—S.E.;
- Road safety (e.g., human factor in case of conventional vehicles, hacking in case of autonomous vehicles)—R.S.;
- Time value (due to exploitation of travel time when using an autonomous car as discharged from driving, traffic congestion reduction, etc.)—T.V.;
- Construction, operation and maintenance infrastructure cost—I.C.;
- Sense of comfort and safety (e.g., due to "discharge" from driving or searching a parking place in case of autonomous vehicles or, on the contrary, fear of "conceding" the vehicle control to a "robot")—C.S.;
- Natural resource consumption (due to vehicle energy efficiency, less transport waste, etc.)—N.R.

The experts were provided with the criteria list, along with explanations integrating the information included in Sections 2.2 and 2.3. This part was placed before the tables with the pair-wise comparisons in the questionnaires, so that the experts would have clearly understood what exactly they should compare before proceeding, taking into account all the decision problem parameters, both at criteria and at alternatives level.

The hierarchical structure of the decision problem according to AHP (Section 2.4.1) is shown in Figure 2, with the overall goal at the top, the criteria at the lower level and the alternatives at the lowest level.

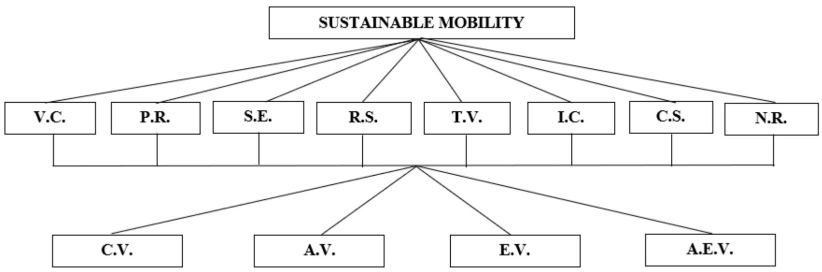

Figure 2. Hierarchical structure according to AHP.

3.6. Criteria Weights Extraction

After having structured the hierarchy of the problem, 28 criteria pair-wise comparisons, an indicative part of which is shown in Table 2, were executed by each expert, based on the 9-level Saaty scale (Table 3), according to AHP (Section 2.4.1).

Table 2. Indicative part of the criteria pair-wise comparisons with regard to their contribution to the overall goal achievement.

The Criterion on the Left Is More Important Than the One on the Right (Select the Intensity of Relative Importance)									Equivalent Importance of the Two Criteria	The Criterion on the Right Is More Important than the One on the Left (Select the Intensity of Relative Importance)								
Pollutant emissions	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Road safety

Table 3. Relative importance scale for the criteria in terms of their contribution to the overall goal achievement [15].

Intensity of Importance	Definition
1	Equivalent importance of the two criteria
3	Moderate importance of the one over the other
5	Strong importance of the one over the other
7	Very strong importance of the one over the other
9	Extreme importance of the one over the other
2, 4, 6, 8	Intermediate values between the aforementioned ones

The aggregation of the experts' answers is realized through the application of the "aggregation of individual judgments method", as described in Section 2.4.4, while the consistency of the answers is checked through the calculation of the AHP consistency ratio CR (Section 2.4.1). The input data based on the experts' answers, as well as the geometric mean value in every case, are shown in Table 4. It should be noted that if the criterion on the left is selected by the experts during the pair-wise comparisons (an indicative part of which is shown in Table 2), the selected value is introduced in the analysis, while if the criterion on the right is selected, the reverse value of the selected one is introduced in the analysis.

Table 4. Experts' judgment and geometric mean values for the compared (in pairs) criteria.

CRITERIA/EXPERTS	EXP1	EXP2	EXP3	EXP4	EXP5	EXP6	EXP7	EXP8	EXP9	EXP10	EXP11	EXP12	G.M.
V.C. OVER P.R.	1/3	1/5	1	3	6	2	1/7	5	1/8	4	1/7	1/2	0.7923
V.C. OVER S.E.	1/4	1/3	3	4	7	3	3	7	1/7	7	1/5	2	1.5389
V.C. OVER R.S.	1/6	1/7	1/5	1/5	1/4	1/4	1/5	1/5	1/8	1/3	1/3	1/6	0.2050
V.C. OVER T.V.	3	1/5	1	1	5	1/4	1	5	1/7	1/4	1/4	2	0.7983
V.C. OVER I.C.	1/2	1	1/3	3	5	3	6	5	7	6	1	1	2.1443
V.C. OVER C.S.	6	1/4	1/4	1	5	1/3	1/5	1/7	7	4	1/3	1/3	0.7859
V.C. OVER N.R.	1/3	1/3	1	1	1	1	1/2	3	1	1	1	1/3	0.7859
P.R. OVER S.E.	3	3	3	4	6	5	7	1/7	5	1/3	3	3	2.4578
P.R. OVER R.S.	1/3	1/3	1/3	1/5	1/5	1/3	1/7	1/8	1/8	1/3	1/3	1/4	0.2365
P.R. OVER T.V.	1	1	1	1	1	1/2	1	1	7	1/2	7	3	1.3503
P.R. OVER I.C.	1	4	1	3	3	4	5	1/3	4	3	8	4	2.5925
P.R. OVER C.S.	5	3	1/3	5	1/2	4	1/5	1/5	3	1/5	4	1	1.1396
P.R. OVER N.R.	1/2	1	2	4	1	2	5	1	1	1/2	1	1	1.2836
S.E. OVER R.S.	1/5	1/3	1/5	1/5	1/8	1/5	1/7	1/8	1/7	1/4	1/5	1/7	0.1807
S.E. OVER T.V.	3	1	1/3	1/2	1/6	1/5	1/7	1/6	1/6	1/5	5	1	0.4484
S.E. OVER I.C.	3	2	1/3	1	1	1/3	1	1	1/5	1/2	6	1	0.9265
S.E. OVER C.S.	5	3	1/5	1/3	1/5	1	1/4	1/8	1/4	1/3	3	1/5	0.5104
S.E. OVER N.R.	1/2	2	1	2	1/4	1/3	1/5	1/6	1	1/4	1	1	0.5779
R.S. OVER T.V.	7	5	7	3	7	2	6	8	8	3	3	6	4.9442
R.S. OVER I.C.	8	7	7	5	8	6	6	8	9	4	6	9	6.7394
R.S. OVER C.S.	7	2	5	3	4	3	2	8	7	4	6	5	4.2411
R.S. OVER N.R.	2	3	7	5	5	4	5	8	5	3	5	5	4.4663
T.V. OVER I.C.	3	1	1	3	6	5	3	7	6	1/2	5	1	2.5752
T.V. OVER I C.S.	3	2	1/3	2	1/4	3	3	1/5	5	4	1/4	1/4	1.0699
T.V. OVER N.R.	1/2	1	1	1/3	1	5	2	1	1	4	1	1/3	1.0688
I.C. OVER C.S.	3	1/2	1/3	1/5	1/6	3	1/5	1/7	5	1/4	1/3	1/4	0.4798
I.C. OVER N.R.	1/3	1/2	2	1/2	1	1/3	1/4	1/3	1/2	4	1/4	1/3	0.5503
C.S. OVER N.R.	1/5	2	3	1/4	1	1/3	4	4	1	1	1/2	1	0.9816

The calculated geometric mean values, as shown in Table 4, constitute the input data for the AHP pair-wise comparison matrix and, thus, for the normalized comparison matrix (derived as described in Section 2.4.1), as shown in Tables 5 and 6, respectively, while the calculated priority vector (relation (2)) for the criteria (criteria weights), as well as the respective consistency control (Section 2.4.1, CR < 0.10), are also shown in Table 6.

Table 5. Pair-wise comparison matrix for the criteria.

	V.C.	P.R.	S.E.	R.S.	T.V.	I.C.	C.S.	N.R.
V.C.	1.0000	0.7923	1.5389	0.2050	0.7983	2.1443	0.7859	0.7859
P.R.	1.2621	1.0000	2.4578	0.2365	1.3503	2.5925	1.1396	1.2836
S.E.	0.6498	0.4069	1.0000	0.1807	0.4484	0.9265	0.5104	0.5779
R.S.	4.8778	4.2283	5.5330	1.0000	4.9442	6.7394	4.2411	4.4663
T.V.	1.2527	0.7406	2.2300	0.2023	1.0000	2.5752	1.0699	1.0688
I.C.	0.4664	0.3857	1.0793	0.1484	0.3883	1.0000	0.4798	0.5503
C.S.	1.2723	0.8775	1.9593	0.2358	0.9347	2.0842	1.0000	0.9816
N.R.	1.2723	0.7791	1.7303	0.2239	0.9356	1.8171	1.0188	1.0000

Table 6. Normalized pair-wise comparison matrix, priority vector and consistency control, for the criteria.

	V.C.	P.R.	S.E.	R.S.	T.V.	I.C.	C.S.	N.R.	PRIORITY VECTOR (W)
V.C.	0.0830	0.0860	0.0878	0.0843	0.0739	0.1079	0.0767	0.0734	0.0841
P.R.	0.1047	0.1086	0.1402	0.0972	0.1250	0.1304	0.1112	0.1198	0.1171
S.E.	0.0539	0.0442	0.0570	0.0743	0.0415	0.0466	0.0498	0.0539	0.0527
R.S.	0.4047	0.4591	0.3157	0.4111	0.4578	0.3390	0.4139	0.4168	0.4023
T.V.	0.1039	0.0804	0.1272	0.0831	0.0926	0.1295	0.1044	0.0998	0.1026
I.C.	0.0387	0.0419	0.0616	0.0610	0.0360	0.0503	0.0468	0.0514	0.0484
C.S.	0.1056	0.0953	0.1118	0.0969	0.0865	0.1048	0.0976	0.0916	0.0988
N.R.	0.1056	0.0846	0.0987	0.0920	0.0866	0.0914	0.0994	0.0933	0.0940
λ_{max} = 8.0847, CI = 0.0121, CR = 0.0086 < 0.10									

3.7. Alternatives Evaluation (Pair-Wise Comparison), with Regard to Each Criterion

The next step is the evaluation of the alternatives in terms of preference with regard to each criterion, which is realized by the group of experts, through pair-wise comparison. The same process followed for the criteria is now followed for the alternatives. As in the case of the criteria, the alternatives are compared in pairs, on the basis of the 9-level scale of Saaty—this time, in terms of preference instead of importance, as shown in Table 7. An indicative part of these 48 pair-wise comparisons (pair-wise comparison of the 4 alternatives, with regard to each one of the 8 criteria) is shown in Table 8. The same question (with regard to the criterion) is repeated for the comparison of all the pairs of alternatives included in Table 8, with regard to each one of the eight criteria.

Table 7. Relative preference scale for the alternatives with regard to each criterion (Saaty, 1980).

Intensity of Preference	Definition
1	Indifference of preference
3	Moderate preference relation
5	Strong preference relation
7	Very strong preference relation
9	Absolute preference relation
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Exactly the same process described for the criteria in Section 3.6 is followed for the alternatives. The input data based on the experts' answers, as well as the geometric mean value for each one of the criteria, are shown in Table 9, and the comparison matrices in Table 10. The normalized comparison matrix of the alternatives, the priority vector, as well as the consistency control, in terms of each criterion, are shown in Table 11.

Table 8. Indicative part of alternatives pair-wise comparison with regard to each criterion.

With Regard to the Criterion "Acquisition, Operation and Maintenance Vehicle Cost"																		
The Alternative on the Left Is Preferable to the One on the Right (Select the Degree of Relative Preference)									**Indifference of Preference**	**The Alternative on the Right Is Preferable to the One on the Left (Select the Degree of Relative Preference)**								
Conventional vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Autonomous vehicles
Conventional vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Electric vehicles
Conventional vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Autonomous electric vehicles
Autonomous vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Electric vehicles
Autonomous vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Autonomous electric vehicles
Electric vehicles	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Autonomous electric vehicles

Table 9. Expert judgment and geometric mean values for the compared alternatives, with regard to each criterion.

V.C.: ALTERNATIVES/ EXPERTS	EXP1	EXP2	EXP3	EXP4	EXP5	EXP6	EXP7	EXP8	EXP9	EXP10	EXP11	EXP12	GEOM. MEAN
C.V. OVER A.V.	5	6	7	5	7	6	6	5	5	6	6	4	5.6007
C.V. OVER E.V.	3	3	3	2	2	3	4	2	2	2	3	2	2.5089
C.V. OVER A.E.V.	7	8	8	6	8	8	6	5	6	5	7	5	6.4738
A.V. OVER E.V.	1/4	1/3	1/5	1/3	1/4	1/3	1/5	1/4	1/5	1/6	1/4	1/4	0.2456
A.V. OVER A.E.V.	2	2	2	2	1	2	1	1	2	2	1	2	1.5874
E.V. OVER A.E.V.	7	6	5	6	6	5	5	4	6	6	4	5	5.3455
P.R.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	1/3	1/4	1/5	1/2	1/3	1/4	1/4	1/5	1/3	1/2	1/4	1/2	0.3078
C.V. OVER E.V.	1/7	1/7	1/8	1/8	1/7	1/8	1/8	1/7	1/7	1/7	1/8	1/7	0.1351
C.V. OVER A.E.V.	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/8	1/7	1/9	1/9	0.1146
A.V. OVER E.V.	1/4	1/4	1/5	1/7	1/3	1/2	1/5	1/4	1/3	1/6	1/3	1/4	0.2530
A.V. OVER A.E.V.	1/6	1/6	1/7	1/7	1/9	1/5	1/5	1/7	1/7	1/6	1/4	1/4	0.1688
E.V. OVER A.E.V.	1/3	1/3	1/4	1/4	1/3	1/2	1/3	1/3	1/2	1	1/2	1/2	0.3986
S.E.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	1/3	1/5	1/6	1/2	1/5	1/8	1	1/7	1/5	1	1/3	1/5	0.2831
C.V. OVER E.V.	1	1	2	1	1	1	1	1	1	1	1	1	1.0595
C.V. OVER A.E.V.	1/3	1/5	1/7	1/2	1/5	1/8	1	1/7	1/5	1	1/3	1/5	0.2794
A.V. OVER E.V.	3	3	5	3	3	5	1	3	5	1	2	2	2.6529
A.V. OVER A.E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
E.V. OVER A.E.V.	1/3	1/3	1/6	1	1/4	1/8	1	1/3	1/5	1	1/3	1/4	0.3486
R.S.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	1/3	1/3	1/6	1/7	1/3	1/8	1/8	1/8	1/4	1	1/6	1/4	0.2262
C.V. OVER E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
C.V. OVER A.E.V.	1/3	1/3	1/6	1/7	1/3	1/8	1/8	1/8	1/4	1	1/6	1/4	0.2262
A.V. OVER E.V.	3	3	6	7	3	8	8	8	4	1	6	4	4.4209
A.V. OVER A.E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
E.V. OVER A.E.V.	1/3	1/3	1/6	1/7	1/3	1/8	1/3	1/8	1/4	1	1/6	1/4	0.2455

Table 9. *Cont.*

T.V.: ALTERNATIVES/ EXPERTS	EXP1	EXP2	EXP3	EXP4	EXP5	EXP6	EXP7	EXP8	EXP9	EXP10	EXP11	EXP12	GEOM. MEAN
C.V. OVER A.V.	1/3	1/3	1/5	1/4	1/4	1/8	1/8	1/8	1/6	1/3	1/5	1/3	0.2155
C.V. OVER E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
C.V. OVER A.E.V.	1/3	1/3	1/5	1/4	1/5	1/8	1/8	1/8	1/6	1/3	1/5	1/3	0.2116
A.V. OVER E.V.	3	3	5	4	3	8	7	8	5	3	5	3	4.4122
A.V. OVER A.E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
E.V. OVER A.E.V.	1/3	1/3	1/5	1/4	1/4	1/8	1/6	1/8	1/5	1/3	1/3	1/3	0.2339
I.C.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	5	5	6	1	7	6	4	5	4	3	4	5	4.2013
C.V. OVER E.V.	3	2	7	2	5	1	1	5	3	1	3	3	2.4896
C.V. OVER A.E.V.	7	6	8	2	9	6	4	5	4	3	6	7	5.1713
A.V. OVER E.V.	1	1/3	1/3	1/2	1/3	1/4	1/3	1	1/2	1/3	1	1/2	0.4740
A.V. OVER A.E.V.	3	3	3	2	1	1	1	5	2	1	2	3	1.9613
E.V. OVER A.E.V.	2	3	3	1	6	6	3	5	3	4	2	2	2.9676
C.S.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	1/5	1/5	1/4	1/5	1	2	1/8	1/8	2	1/2	1/2	1/3	0.3844
C.V. OVER E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
C.V. OVER A.E.V.	1/5	1/5	1/6	1/5	1	2	1/8	1/8	2	1/2	1/2	1/3	0.3717
A.V. OVER E.V.	3	5	3	4	3	1	6	7	1/3	4	3	2	2.7430
A.V. OVER A.E.V.	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
E.V. OVER A.E.V.	1/3	1/5	1/3	1/5	1	1	1/6	1/7	3	1/4	1/3	1/3	0.3791
N.R.: ALTERNATIVES/ EXPERTS	**EXP1**	**EXP2**	**EXP3**	**EXP4**	**EXP5**	**EXP6**	**EXP7**	**EXP8**	**EXP9**	**EXP10**	**EXP11**	**EXP12**	**GEOM. MEAN**
C.V. OVER A.V.	1/2	1/4	1/5	1/3	1/3	1/3	1/3	1/5	1/2	1/3	1/2	1/3	0.3308
C.V. OVER E.V.	1/7	1/5	1/7	1/8	1/8	1/6	1/8	1/8	1/6	1/7	1/6	1/7	0.1460
C.V. OVER A.E.V.	1/8	1/6	1/8	1/9	1/9	1/7	1/9	1/9	1/8	1/8	1/7	1/8	0.1259
A.V. OVER E.V.	1/4	1/3	1/3	1/5	1/5	1/3	1/4	1/4	1/3	1/2	1/4	1/4	0.2809
A.V. OVER A.E.V.	1/6	1/3	1/5	1/6	1/7	1/4	1/2	1/7	1/4	1/2	1/5	1/5	0.2314
E.V. OVER A.E.V.	1/2	1/3	1/4	1/3	1/3	1/2	1/3	1/3	1/2	1	1/2	1/2	0.4223

Table 10. Comparison matrix of the alternatives, in terms of each criterion.

V.C.	C.V.	A.V.	E.V.	A.E.V.
C.V.	1	5.6007	2.5089	6.4738
A.V.	0.1785	1	0.2456	1.5874
E.V.	0.3986	4.0712	1	5.3455
A.E.V.	0.1545	0.6300	0.1871	1
P.R.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	0.3078	0.1351	0.1146
A.V.	3.2488	1	0.2530	0.1688
E.V.	7.4005	3.9520	1	0.3986
A.E.V.	8.7274	5.9237	2.5089	1
S.E.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	0.2831	1.0595	0.2794
A.V.	3.5328	1	2.6529	1.0000
E.V.	0.9439	0.3770	1	0.3486
A.E.V.	3.5785	1.0000	2.8690	1
R.S.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	0.2262	1.0000	0.2262
A.V.	4.4209	1	4.4209	1.0000
E.V.	1.0000	0.2262	1	0.2455
A.E.V.	4.4209	1.0000	4.0739	1

Table 10. *Cont.*

T.V.	C.V.	A.V.	E.V.	A.E.V.
C.V.	1	0.2155	1.0000	0.2116
A.V.	4.6398	1	4.4122	1.0000
E.V.	1.0000	0.2266	1	0.2339
A.E.V.	4.7269	1.0000	4.2756	1
I.C.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	4.2013	2.4896	5.1713
A.V.	0.2380	1	0.4740	1.9613
E.V.	0.4017	2.1097	1	2.9676
A.E.V.	0.1934	0.5099	0.3370	1
C.S.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	0.3844	1.0000	0.3717
A.V.	2.6013	1	2.7430	1.0000
E.V.	1.0000	0.3646	1	0.3791
A.E.V.	2.6907	1.0000	2.6377	1
N.R.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**
C.V.	1	0.3308	0.1460	0.1259
A.V.	3.0233	1	0.2809	0.2314
E.V.	6.8472	3.5602	1	0.4223
A.E.V.	7.9445	4.3208	2.3681	1

Table 11. Normalized pair-wise comparison matrix of the alternatives, priority vector and consistency control, in terms of each criterion.

V.C.	C.V.	A.V.	E.V.	A.E.V.	PRIORITY VECTOR (W)
C.V.	0.5397	0.5397	0.5397	0.5397	0.5397
A.V.	0.0910	0.0910	0.0910	0.0910	0.0910
E.V.	0.3038	0.3038	0.3038	0.3038	0.3038
A.E.V.	0.0655	0.0655	0.0655	0.0655	0.0655
λ_{max} = 4.1037, CI = 0.0346, CR = 0.0392 < 0.10					
P.R.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.0491	0.0275	0.0347	0.0681	0.0448
A.V.	0.1594	0.0894	0.0649	0.1004	0.1035
E.V.	0.3632	0.3534	0.2566	0.2370	0.3025
A.E.V.	0.4283	0.5297	0.6438	0.5945	0.5491
λ_{max} = 4.1743, CI = 0.0581, CR = 0.0659 < 0.10					
S.E.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.1104	0.1064	0.1397	0.1063	0.1157
A.V.	0.3901	0.3759	0.3499	0.3805	0.3741
E.V.	0.1042	0.1417	0.1319	0.1326	0.1276
A.E.V.	0.3952	0.3759	0.3784	0.3805	0.3825
λ_{max} = 4.0160, CI = 0.0053, CR = 0.0060 < 0.10					
R.S.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.0922	0.0922	0.0953	0.0915	0.0928
A.V.	0.4078	0.4078	0.4212	0.4046	0.4103
E.V.	0.0922	0.0922	0.0953	0.0993	0.0948
A.E.V.	0.4078	0.4078	0.3882	0.4046	0.4021
λ_{max} = 4.0010, CI = 0.0003, CR = 0.0004 < 0.10					

Table 11. *Cont.*

T.V.	C.V.	A.V.	E.V.	A.E.V.	PRIORITY VECTOR (W)
C.V.	0.0880	0.0883	0.0936	0.0865	0.0891
A.V.	0.4082	0.4095	0.4128	0.4089	0.4099
E.V.	0.0880	0.0928	0.0936	0.0956	0.0925
A.E.V.	0.4159	0.4095	0.4000	0.4089	0.4086
λ_{max} = 4.0012, CI = 0.0004, CR = 0.0004 < 0.10					
I.C.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.5455	0.5372	0.5789	0.4659	0.5319
A.V.	0.1298	0.1279	0.1102	0.1767	0.1362
E.V.	0.2191	0.2698	0.2325	0.2673	0.2472
A.E.V.	0.1055	0.0652	0.0784	0.0901	0.0848
λ_{max} = 4.0440, CI = 0.0147, CR = 0.0166 < 0.10					
C.S.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.1371	0.1398	0.1355	0.1351	0.1369
A.V.	0.3567	0.3638	0.3716	0.3635	0.3639
E.V.	0.1371	0.1326	0.1355	0.1378	0.1358
A.E.V.	0.3690	0.3638	0.3574	0.3635	0.3634
λ_{max} = 4.0004, CI = 0.000, CR = 0.0001 < 0.10					
N.R.	**C.V.**	**A.V.**	**E.V.**	**A.E.V.**	**PRIORITY VECTOR (W)**
C.V.	0.0531	0.0359	0.0385	0.0707	0.0496
A.V.	0.1607	0.1086	0.0740	0.1301	0.1183
E.V.	0.3639	0.3865	0.2635	0.2373	0.3128
A.E.V.	0.4222	0.4690	0.6240	0.5619	0.5193
λ_{max} = 4.1339, CI = 0.0446, CR = 0.0506 < 0.10					

3.8. Formulation of the Decision Matrix for the Application of VIKOR and TOPSIS

The priority vectors of the alternatives (Table 11), expressing their performance with regard to each criterion, constitute the input data for the decision matrix used for the application of TOPSIS and VIKOR (Table 12), in order to derive the overall ranking of the alternatives.

Table 12. Decision matrix for the application of TOPSIS and VIKOR for the overall ranking of the alternatives.

	V.C.	P.R.	S.E.	R.S.	T.V.	I.C.	C.S.	N.R.
C.V.	0.5397	0.0448	0.1157	0.0928	0.0891	0.5319	0.1369	0.0496
A.V.	0.0910	0.1035	0.3741	0.4103	0.4099	0.1362	0.3639	0.1183
E.V.	0.3038	0.3025	0.1276	0.0948	0.0925	0.2472	0.1358	0.3128
A.E.V.	0.0655	0.5491	0.3825	0.4021	0.4086	0.0848	0.3634	0.5193

It should be noted that the form of the questions posed to the experts (asking which alternative is preferable to the other) in pair-wise comparison questionnaires for the alternatives comparison (an indicative part of which is shown in Table 8) makes all the criteria benefit criteria (benefit functions).

3.9. Application of TOPSIS for the Alternatives Ranking

Based on Table 12, the weighted normalized decision matrix for the application of TOPSIS (Section 2.4.2), according to relation (7), using the criteria weights (W) of Table 6, is shown in Table 13.

Table 13. Weighted normalized decision matrix for TOPSIS application.

	V.C.	P.R.	S.E.	R.S.	T.V.	I.C.	C.S.	N.R.
C.V.	0.0454	0.0053	0.0061	0.0373	0.0091	0.0258	0.0135	0.0047
A.V.	0.0077	0.0121	0.0197	0.1651	0.0421	0.0066	0.0359	0.0111
E.V.	0.0256	0.0354	0.0067	0.0381	0.0095	0.0120	0.0134	0.0294
A.E.V.	0.0055	0.0643	0.0201	0.1617	0.0419	0.0041	0.0359	0.0488

The values of A^+ and A^- for TOPSIS are calculated according to relations (8) and (9):

$$A^+ = \{0.0454 \quad 0.0643 \quad 0.0201 \quad 0.1651 \quad 0.0421 \quad 0.0258 \quad 0.0359 \quad 0.0488\}$$

$$A^- = \{0.0055 \quad 0.0053 \quad 0.0061 \quad 0.0373 \quad 0.0091 \quad 0.0041 \quad 0.0134 \quad 0.0047\}$$

The calculated values of S_i^+, S_i^- and c_i^+ for TOPSIS, according to relations (10)–(12), respectively, as well as the ranking (maximum c_i^+ value $\rightarrow$ best alternative) of the alternatives, are shown in Table 14.

Table 14. Calculated values of S_i^+, S_i^- and c_i^+ and alternative ranking according to TOPSIS.

	S_i^+	S_i^-	c_i^+	Ranking
C.V.	0.1534	0.0454	0.2283	4
A.V.	0.0770	0.1349	0.6364	2
E.V.	0.1402	0.0446	0.2413	3
A.E.V.	0.0455	0.1506	0.7680	1

As shown in Table 14, autonomous electric vehicles constitute the optimum solution within the framework of sustainable mobility, according to the AHP-TOPSIS model.

3.10. Application of VIKOR for the Alternatives Ranking

As regards VIKOR application (Section 2.4.3), based on Table 12, f^*_j and f^-_j values are calculated as follows, according to relations (13) and (14):

$$f^*_j = max_i(x_{ij}) = \{0.5397\ 0.5491\ 0.3825\ 0.4031\ 0.4099\ 0.5319\ 0.3639\ 0.5193\}$$

$$f^-_j = min_i(x_{ij}) = \{0.0655\ 0.0448\ 0.1157\ 0.0999\ 0.0891\ 0.0848\ 0.1358\ 0.0496\}$$

The calculated values of S_i, R_i and Q_i for VIKOR, for $v = 0.5$, adopting the criteria weights (W) of Table 6, according to relations (15)–(18), as well as the ranking (minimum value $\rightarrow$ best alternative) based on these values, are shown in Table 15.

Table 15. S_i, R_i and Q_i values and alternatives ranking according to VIKOR.

	C.V.	A.V.	E.V.	A.E.V.
$\mathbf{S_i}$	0.8669	0.3078	0.8217	0.1437
$\mathbf{R_i}$	0.4023	0.1035	0.3998	0.0841
$\mathbf{Q_i}$	1.0000	0.1440	0.9648	0.0000
$\mathbf{RankS_i}$	4	2	3	1
$\mathbf{RankR_i}$	4	2	3	1
$\mathbf{RankQ_i}$	4	2	3	1

Based on Table 15, and having executed the control for the two conditions (as defined in Section 2.4.3) of the acceptable advantage ($0.1440 - 0 = 0.1440 < 1/(m - 1) = 1/(4 - 1) = 1/3 = 0.3333$, so the condition is not met) and of the acceptable stability (the alternative ranked first in terms of Q_i is also ranked first in terms of S_i and R_i, so the condition is met), both autonomous electric vehicles and autonomous vehicles constitute the optimum solution within the framework of sustainable mobility, according to the AHP-VIKOR model.

3.11. Reveal of the Optimum Solution

The application of the AHP-TOPSIS model results in autonomous electric vehicles as the optimum solution, while in the AHP-VIKOR case, the alternative of autonomous electric vehicles is ranked first in terms of Q_i, but the condition of acceptable advantage of Section 2.4.3 leads to the "co-existence" of autonomous electric and autonomous vehicles in the first rank. Thus, according to the logic diagram of Figure 1, the *1/2m* condition must be checked. The condition is met (as $0.7680 - 0.6364 = 0.1316 > 1/2 \times 4 = 0.125$), so autonomous electric vehicles finally emerge as the optimum solution within the framework of sustainable mobility.

4. Discussion and Conclusions

In this study, a new decision-aiding methodology is applied for the evaluation of autonomous, electric, autonomous electric and conventional vehicles with regard to a set of environmental, social and economic criteria, with the participation of a group of experts in the process. Such a problem consists, among others, of alternatives with a low maturity level, a fact that increases the difficulty of their evaluation at the present time, with the expected impacts at environmental, social and economic levels characterized by considerable uncertainty in the existing literature. However, a holistic evaluation of these new technologies within the framework of sustainable mobility, even at a preliminary level, is conducted. The results show whether these new technologies can truly perform better than conventional ones in terms of sustainable mobility, which one of them constitutes the optimum solution, as well as how each alternative performs in terms of each evaluation criterion (such as road safety or air pollutants and greenhouse gas emissions). Given the low maturity level of these technologies, it would be interesting to re-conduct the analysis in the future, when the widespread entrance of these technologies into road networks will be even closer, with updated information, and to compare the results.

Autonomous electric vehicles, characterized by the optimum overall performance, emerge as the optimum sustainable mobility solution. As regards the performance with regard to each criterion, according to Table 11, autonomous vehicles (either electric or with fossil fuels) are characterized by the highest performance in terms of road safety, time value, sense of comfort and safety, as well as social equity. Autonomous electric vehicles are characterized by the highest performance in terms of air pollutants and greenhouse gas emissions, as well as natural resource consumption, and by the lowest performance in terms of acquisition, operation and maintenance vehicle cost, as well as construction, operation and maintenance infrastructure cost. Conventional vehicles seem to have the worst performance with regard to all the criteria, except the ones relating to vehicle and infrastructure cost. Electric vehicles are characterized by high performance in terms of air pollutants and greenhouse gas emissions, ranked second (after autonomous electric vehicles) with regard to these criteria. Concerning vehicle and infrastructure cost, electric vehicles are also ranked second (after conventional ones). As for the rest of the criteria, despite the remarkable difference between autonomous (either electric or with fossil fuels) and conventional vehicles, it seems that there is no significant difference between conventional and electric ones. According to Table 6, road safety and air pollutants and greenhouse gas emissions emerged as the most important criteria, followed by time value, sense of comfort and safety, natural resource consumption, acquisition, operation and maintenance vehicle cost, social equity and construction, operation and maintenance infrastructure cost.

It is worth commenting on the impressively high performance of autonomous (either electric or with fossil fuels) vehicles in terms of certain criteria, based on Table 11, as well as in terms of certain "special" criteria. It seems that the experts "invest", to a large extent, in autonomous vehicles in terms of road safety. As already mentioned in Section 2.2, autonomous vehicles are, indeed, expected to lead to a remarkable reduction in road accidents (from 40% to 90%), given that more than 90% of them are due to human error, but there are also dangers, especially during the transitional period, such as software breakdown, hacking, etc., that should be taken into account. This conviction is depicted in Table 9, where all the experts, except one (for whom the impact on road safety will be neutral due to the other dangers, at least with present data), consider autonomous vehicles (either electric or not) as much safer than conventional ones, which seem to have remarkably low performance with regard to road safety. The experts explained that, apart from the assumption that autonomous vehicles will circulate in separate lanes (not in mixed flow with conventional ones), their circulation will be permitted only after having been adequately tested, with any issues relating to cybersecurity and relevant risks minimized, so the expected positive impact outweighs the negative one, according to them. Moreover, autonomous vehicles (either electric or not) are expected to have positive impacts on time value of users, mainly due to the opportunity for the user to exploit travel time in a more efficient way, given the discharge from driving or searching for a parking place, due to the expectation for a smarter mobility (e.g., platoons) leading to traffic congestion reduction, etc. Concerning the criterion of social equity, it could be characterized as special in relation to the advent of autonomous vehicles (a fact depicted in the experts' judgment as well, as shown in Table 9, with two experts considering this impact to be neutral), as, on the one hand, social equity could be strengthened due to the expected facilitation of mobility for the elderly or people with impairments, but, on the other hand, the high acquisition cost could exacerbate social inequalities. According to Table 11, it seems that the impact on social equity will finally be positive, with the experts claiming that subsidies for the elderly or people with impairments would be examined in case of reduced purchase potential. The criterion of sense of comfort and safety is another special criterion, as depicted in Table 9, as some people may feel safer and more comfortable in an autonomous vehicle, e.g., due to road safety improvement perception, discharge from driving or from parking place searching and parking procedure, which often cause stress to the driver, according to relevant surveys (Section 2.2), while others might not feel safe or comfortable when conceding vehicle control to a "robot" (Section 2.2). Based on Table 11, the performance of autonomous vehicles (either electric or not) with regard to this criterion is expected to be high. Finally, as mentioned in Sections 2.2 and 2.3, and as depicted in Table 11, electric vehicles are related to increased energy efficiency, less transport waste and reduced air pollutants and greenhouse gas emissions, even in the case of conventional energy sources, while autonomous vehicles may also lead to less fuel consumption, less transport waste, air pollution, etc. (e.g., due to eco-driving, platoons, lighter elements in the case of road safety improvement), a fact also depicted in Table 11. Thus, the combination of these technologies "launches" the performance of autonomous electric vehicles in terms of air pollutants and greenhouse gas emissions and natural resource consumption at the top, as shown in Table 11, with conventional vehicles characterized by the lowest, by far, performance in terms of these criteria.

The application of a scientifically documented process for the support of decision-making in the transport sector is of high importance, especially in times of economic "stringency" and environmental crisis, towards the minimization of "wrong" decisions and proper resource management. The decision-aiding methodology presented and applied in this work, especially appropriate for sustainable mobility project evaluation, allows for the reveal of the optimum solution to be promoted and funded, with a view to maximizing benefit and minimizing cost at social, environmental and economic level. In this sense, the proposed methodology constitutes an important tool for analysts and decision-makers in various sustainability sectors, and especially in the key sector of transportation. The combined application of the two hybrid MCA models creates a more solid background towards optimum decision-making compared to the application of each method or model separately, as well as to other evaluation methods, such as CBA, exploiting the strengths of each method, allowing for the inclusion of quantitative and qualitative, and tangible and intangible, parameters in the analysis and minimizing subjectivity, with the participation of a group of experts. The analyst is provided with a better overview of the data and results, the experts' answers generating inconsistency can be easily identified, and, if necessary, the in-depth comprehension of the problem and the related parameters is ensured, while the methods "engaged" in the process are easy to understand and to apply. Software production is recommended as a future prospect, so that the application of the proposed methodology can be made even easier in practice for project evaluation, appraisal and funding (by Municipalities, Ministries, Companies, etc.) in various sectors, including the transport sector.

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