



Article Determining Electric Vehicle Charging Station Location Suitability: A Qualitative Study of Greek Stakeholders Employing Thematic Analysis and Analytical Hierarchy Process

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Abstract: Shifting from a fossil-fueled to an eco-friendly vehicle fleet in cities could pave the way towards a more sustainable future. Electric Vehicles (EVs) should thus be prioritized, so that they could replace conventional vehicles gradually. In this context, an EV-accommodating infrastructure, which ensures the functionality of the entire system, is essential. This study aims to develop a methodological framework to identify suitable locations for the deployment of EV charging points in urban environments. To meet this objective, we acquired a mixed method approach including a systematic literature review, 12 semistructured stakeholder interviews which were thematically analyzed, and an Analytical Hierarchy Process (AHP). The outcome is a spatial model function, which consists of parameters and weights for estimating the suitability of each urban road link that will allow the establishment of EV charging points. Results show that the key location selection factors are: transport hubs, marked or controlled parking spaces, and points of interest. The less significant factor is public services. Therefore, there is a preference, in stakeholder level, for transport features over the land use ones (69% over 31%). Although this research is conducted in Greece, we intend to suggest methods and generate valuable findings that may be valid and generalizable for a more global context.

Keywords: electric vehicles; electric chargers; spatial analysis; analytical hierarchy process; participative methods; qualitative research

1. Introduction

Cities are on the verge of a historic transformation [1] that will be founded on smart interventions [2] underpinned by resilience and sustainability goals [3]. The transport sector plays an important role, particularly related to the environment, as it is responsible for almost one-quarter of energy-related emissions [4]. Conventional transport systems dominated by private cars (which are typically vehicles with internal combustion engines) have generated severe environmental consequences such as scarcity of oil [5], deterioration of air quality, and greenhouse gas (GHG) emissions [6,7]. Furthermore, fossil fuel usage, namely, diesel and petrol/gasoline, not only lead to environmental problems, but also affect public health significantly [8,9].

Therefore, the adoption of strategies and policies that might strengthen cities' efficiency and sustainability is necessary. Due to the technological advance, new ways and opportunities emerge [10]. Now, a shift from the conventional to a more environmentally friendly vehicle fleet in urban environments could be an adequate driver for a more viable future [11]. Clean energy and decarbonization should be fundamental pillars in this direction, and key to this shift is electric mobility [12], and specifically the adoption of electric



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). vehicles (EVs) [13]. Although EVs origin from the past [6] they are now becoming the next automotive technology to be widely diffused in society [14]. EVs that are defined as any passenger vehicle that uses energy drawn from the electric grid and stores it on board for propulsion [15–18] comprise a major way to reduce fossil fuel consumption and to decrease air pollutants and GHGs. The electrification of cars is a measure reducing significantly the adverse environmental impacts of transport [19] and improving its performance [20] as electric propulsion is energy efficient, and does not cause local emissions and reduces noise [21].

Studies adopting a life cycle approach [22] determined emissions' reduction from replacing fossil fuel powered vehicles by EVs. This is especially prominent in several European countries [23,24]. In this direction, Hawkins et al. [17] illustrated that EVs can offer a 10% to 24% potential decline in global warming impact compared to conventional vehicles. In 2017, the share of EVs existing in the car market reached 1.8%, depicting a compelling increase when compared to its counterpart in 2010 [25]. Tellingly, according to Cooper and Schefter [26] this upturn is expected to continue, thus exceeding the 20% of the total market share, by the year 2030.

However, the adoption of EVs on a large scale is expected to give rise to both challenges and opportunities from technical and economic perspectives [27]; future research should be conducted to capture the readiness-to-adapt levels accurately [28]. The most critical barriers are economic restrictions and cost concerns [29], building infrastructure for charging, improving the electricity distribution grid, practicability issues, as well as legal and privacy issues regarding coordinated "smart" charging systems [30]. Among these, the timing and pattern of EVs seem to play a pivotal role [31].

According to many related studies [32–40], the lack of charging infrastructure or their slower roll-out hinders the expansion and diffusion of EVs in the car market considerably. Especially in this period in which transition to electric mobility is accelerating, Electric Vehicle Charging Stations (EVCSs) could be regarded as a necessity [41]. Electromobility is a particularly complex eco-system, but supporting a robust EV-charging infrastructure that prioritizes these vehicles (and the use of renewable energy sources) is a fundamental step towards the right direction [42].

Consumer surveys from across different global markets show that the lack of (adequate) refueling infrastructure will be a crucial restraint for the adoption of EVs [43,44]. Indeed, a study conducted in Japan found that owners of EVs would not have bought one if there was not an adequate level of public station availability [45]. The absence of an efficient EV charging network results in the range anxiety effect [46]. Range anxiety refers to the concerns and fears of the drivers while driving the vehicle [47]. Alternatively, Eberle and von Helmolt [48] define range anxiety as the fear of insufficient range to reach destinations. Therefore, providing the EV users with easy and convenient charging services would be beneficial towards this scope [49–53]. Tellingly, modest public charging opportunities seem to be preferred over the development of longer-range vehicle capabilities [19,54]. To date, many public charging stations have been deployed worldwide and the number increases gradually [49]. Usually, these stations are level 2 (power rates range above 3.7 kW up to 22 kW) or level 3 (above 22 kW) [55].

Charging stations are equally important to vehicles and clean energy provision, as they ensure the functionality of the entire system. That is why a robust method for allocating these charging stations in the urban environment is critical for EV-related growth. Therefore, the main objective of this study is to develop a methodological framework consisting of participative methods to define suitable locations for the establishment of EVCSs in cities. The method should consider spatial data provided by Geographic Information Systems (GIS) that have already been developed in many cities. Therefore, in this study, we attempt to introduce a new evaluation index that defines the suitability of each road link to locate an EVCS. The new index is estimated through a range of spatial criteria. Thus, this paper ultimately aims to identify these criteria by taking into account different perspectives and views that exist among experts and policy-makers (the two critical stakeholder groups), and to create a spatial model function that evaluates the road link suitability based on their informed opinions. Although this research is conducted in Greece the proposed methodological framework could, to some degree, produce valuable findings that are valid in a more generalizable global context.

To meet the previously mentioned objectives, a methodological approach that combines Qualitative Research (QR) and Analytical Hierarchy Process (AHP) is followed. More specifically, by reviewing the literature, we search for spatial criteria that have been utilized in different cities of the world. Afterwards, semistructured interviews with policy-makers, planners, and market experts from Greece are conducted in order to determine a set of criteria that are also applicable in Greek cities. To detect the magnitude of criteria, an evaluation form of pairwise comparisons is distributed to experts. Through this participatory planning process, the experts define a spatial model function, which consists of certain criteria and weights that estimates the suitability of each road link for the establishment of an EV charging point. This combinatorial methodological process differentiates our paper from other similar studies that address the location of EVCSs solely as a mathematical problem. On the contrary, we envisage this process as an issue with multidimensional dynamics that cannot rely only on point-related solutions. Furthermore, this research is distinctly different from others using GIS tools and analysis, as it incorporates qualitative research and participatory methods that provide an extra layer of depth to the findings that reflects real world insights of applied nature by key stakeholders deciding for or planning these interventions. For these reasons therefore, our study adds value and enriches the literature.

The remainder of the paper is structured as follows. In Section 2, the relevant literature is reviewed, followed by analytical presentation of the research methodology in Section 3. The results are presented in Section 4, and finally the discussion and conclusions are presented in Section 5.

2. Literature Review

The academic debate on EVCS deployment issues is attracting more and more attention on a worldwide level [56]. During the last decade, EVCS planning problems have been adequately examined and are still catching the interest of both practitioners and researchers [57,58]. A review by Pagany et al. [59] indicates that the number of articles in 2016 had increased by more than 150% compared to 2010. These studies adopt various techniques and methods for locating the stations, thus composing a multispectral body of literature. Despite their differences, all the EVCS locating approaches have in common that they propose a system of EV charging networks after taking into consideration technical and geographic resources, aiming to facilitate EV users with the lowest energy consumption possible [60].

Most of the studies have incorporated optimal roll-out strategies through taking into account demand and supply data [61]. For example, Oda et al. [62] adopted a mixed method that incorporated queuing theory and cost–benefit analysis for both mitigating the congestion related to quick charging stations and examining the need for installation of new. Another study carried out by Pagani et al. [41] used an agent-based simulation framework along with a georeferenced model of the built infrastructure, aiming to identify the charging behavior of individual EV users as well as the deployment of the EVCSs. When it comes to the supply side allocation, though, many scholars have followed optimization methods, such as integer programming [53,63], genetic algorithms [64], particle swarm optimization, etc. [34] to determine the positions of the EVCSs.

For instance, Huang et al [57] proposed two optimization models for two different charging modes (fast and slow charging) that aim to minimize the total cost while satisfying certain coverage goals. Specifically, the objective of their research was to maximize the captured traffic flow with a given number of charging stations. Sadeghi-Barzani et al. [65] demonstrated a genetic algorithm technique (GA), which found a layout that minimized the total cost of deploying charging stations. Another study by Wang et al. [66] examined the siting and sizing problem of fast charging stations in a highway network, considering

budget constraints and service capacities. Arkin et al. [67] deal with a facility location problem through the use of graph theory, specifically "t-spanning routes". The rationale of their research lies on allocating an adequate number of charging stations along the users' trips. Bouguerra and Layeb [7] employed five Integer Linear Programs based on weighted set covering models, resulting in optimal infrastructure schemes that could be adopted by stakeholders and policy-makers. In line with that, Zhang et al. [68] formulated a classic set covering problem for investigating and optimizing the utilization of EV charging stations. Maximal covering model was also used in a study conducted by Frade et al. [69], aiming to define both the number and the capacity of the new stations. Furthermore, combinatorial methods emerged for achieving better efficiency; Awasthi et al. [70] integrated two popular bionic optimization algorithms. Specifically, a particle swarm optimization (PSO) algorithm was used to re-optimize the suboptimal solution set obtained by the GA. Bian et al. [71] proposed a Mixed Integer Linear Programming (MILP) model based on Geographic Information System (GIS) to establish the ideal location of charging stations in urban environments.

However, the issue of EV charging stations deployment is also a spatial problem, influenced by various conflicting criteria [35]. Therefore, in contrast to the large number of studies that apply mathematical programming and optimizations, there are few works in the context of location analysis that rely on multicriteria analysis and GIS-based methods [38]. Among these, some papers develop a framework for assessing entire areas instead of individual points, thus formulating spatial models [34].

Csiszár et al. [36] used weighted multicriteria methods to evaluate areas and allocate charging stations within an area applying a hexagon-based approach and using a greedy algorithm. In the same direction, Namdeo et al. [43] developed a methodological framework for multidimensional spatial analysis that combines socioeconomic traits and trip characteristics for prioritizing the demand-based public charging stations. Heyman et al. [72] introduces diffusion theory along with GIS analysis tools in order to analyze spatio-temporal clustering of EV charging demand. Through this method, this work develops a framework capable of forecasting spatial patterns of EVCSs in real world conditions. Another interesting research by Victor-Gallardo et al. [55] employed a method that considers supplying charging stations in metropolitan areas and providing their availability in routes connecting distant places, while ensuring the technical feasibility of these locations. Costa et al. [32] proposed the mapping of well-suited sites for EVCSs by using GIS analysis in combination with knowledge from a survey conducted with local EV experts. Zhang et al. [34] formulated a spatial methodology that takes into account a variety of positive and negative factors related to walkability in order to determine optimal position of the charges. Erbas et al. [35] formulated a comprehensive method to determine the potential sites of EVCSs. More specifically, they used a GIS-based MCDMA approach including Fuzzy AHP and TOPSIS method to produce their results. Another relevant study carried out by Huang et al. [49] proposed a novel GIS-assisted optimal design method for renewable powered EV charging stations in high-density cities. In the same page, Efthymioy et al [73] performed a spatial exploration using also a multicriteria analysis technique, and therefore produced a coherent map addressed to stakeholders. Finally, different Multiple-criteria Decision Analysis (MCDA) methods are combined to evaluate EVCS site selection by Wu et al. [74] and Zhao and Li [50].

There are some noticeable approaches that pay considerable attention to participatory methods as well, thus enhancing the engagement of stakeholders and public bodies [75]. Besides, stakeholder analysis techniques offer the opportunity to better understand the decision making process in certain contexts [76]. For instance, Kougias et al. [42] and also Wolbertus [77] used Q-methodology to recognize different perspectives on the future of establishing EV charging infrastructure. In the same context, Costa et al. [78] employed a Multi-Criteria Decision-Making (MCDM), the Weighted Linear Combination (WLC) method, and the Analytical Hierarchy Process (AHP) technique based on the inputs from a group of electric mobility experts, combined with a GIS modeling tool. Last, Costa et al. [79]

also incorporated MCDA method coupled with GIS to detect the opinion of stakeholders coupled with a spatial resolution.

After examining the rich literature related to EV charging stations deployment addressing various and even divergent methods, we proceed to a much more specific process. We now choose several scientific articles that were discussed in the previous paragraphs, published in peer-reviewed journals, which are the most related to our research question. More specifically, we identified 22 criteria, encountered in seven papers dating back from 2012 that adopt multicriteria or participatory approaches. Tellingly, this task can be regarded as a preliminary identification of the proper criteria for EVCSs' location suitability, contributing greatly to the entire research methodology. Table 1 summarizes the main points of these papers: authors, date, criteria, and frequency of one criterion appearing to each of the papers chosen. As it can be observed, the criteria presented belong to seven (7) major categories: Land uses, Sociodemographics, Transport Infrastructure, Mobility, Parking, Energy, and Environment. This variance of categories ensures a holistic view on the issue, thus developing a comprehensive basemap for our research methodology. It is prominent that the main interest of the academic research focuses on sociodemographic characteristics meaning age, income, and population density, on points of interest that attract trips, on road network elements like road width and on energy networks existing in each city. Therefore, the location suitability of EV charging stations is not solely affected by spatial coverage, but it also depends significantly on multitude and even contradicting features.

Criteria Category		Namdeo et al. [43]	Costa et al. [79]	Heyman et al. [72]	Erbas et al. [35]	Zhang et al. [34]	Pagani et al. [41]	Efthymiou et al. [73]	Total
gender	sociodemographics	1	0	0	0	0	0	0	1
age group	sociodemographics	1	1	1	0	0	1	0	4
education level	sociodemographics	0	0	1	0	0	0	0	1
income	sociodemographics	1	1	0	0	1	0	1	4
number of vehicles per household	sociodemographics	0	0	1	0	0	0	0	1
population density	sociodemographics	0	1	0	1	0	0	1	3
number of households	sociodemographics	0	0	1	0	0	0	0	1
number of workplaces	sociodemographics	0	1	1	0	1	0	0	3
green spaces	land uses	0	0	0	0	1	0	0	3
points of interest	land uses	0	1	0	0	1	1	1	4
gas stations	land uses	0	0	0	1	1	0	0	2
road network	transport infrastructure	0	1	0	1	1	0	0	3
public transport stops	transport infrastructure	0	1	0	0	1	0	0	2
walking distance	mobility	0	0	0	0	0	1	0	1
trip origins/destinations	mobility	1	0	0	0	1	0	0	2
parking facilities	parking	0	0	0	0	1	0	1	2
parking property	parking	0	0	1	0	0	0	0	1
energy network	energy	0	0	1	0	0	1	1	3
slope	environment	0	1	0	1	1	0	0	3
proximity to protected areas	environment	0	1	0	1	0	0	0	2
proximity to water resources	environment	0	1	0	1	1	0	0	3
landslide risk	environment	0	1	0	1	0	0	0	2
earthquake risk	environment	0	0	0	1	0	0	0	1

Table 1. Spatial criteria utilized by previous studies.

The methodological framework consists of two main pillars. The first one includes the Qualitative Research (QR), carried out via in-depth semi structured interviews with stakeholders, aiming at identifying the criteria of EVCSs location suitability; these have been also identified by the literature review. The second pillar concerns the development of a spatial model function indicating location suitability through utilizing the Analytical Hierarchy Process (AHP).

3.1. Definition of Link Suitability Index

To evaluate the suitability of each link to establish an EVCs, a suitability index is at first developed. It uses a scale from 0 to 10 in order to identify links with optimal suitability (i.e., 9, 10) and links that are marginally suitable (i.e., 3, 5) or non-suitable (i.e., 0, 1, 2). In essence, the research methodology is not designed to define a very specific set of optimal locations of EVCSs in a city. It is rather an assessment methodology that provides to policy makers an index corresponding to each road link (i.e., the location suitability index). In this planning process, policy-makers will be capable of making the final decisions; they can use the results of this spatial analysis in order to make the most effective decisions.

The selected scale is presented in Table 2. The location suitability index is predefined as an ordinal variable with 11 levels that are classified in five different groups. The median level equals to 5; links with higher or equal suitability to median level are deemed appropriate to establish an EV charging station. At the same time, links with lower index than 3 should be considered as non-selectable by the policy-makers.

DescriptionScoreNon-suitable link[0,3)Marginally suitable link[3,5)Suitable link[5,7)Highly suitable link[7,9)Optimal suitable link[9,10]

Table 2. Location suitability index, scale 0 to 10.

3.2. Selection of Parameters Using Qualitative Methods

The literature review provided an overview regarding the criteria used by previous studies to specify the optimal locations of EVCSs. Some of the identified criteria may not be applicable in Greek cities; mainly due to data availability. In addition, the mobility culture and the urban characteristics differ among countries and cities of the world [80]. Therefore, in order to select the final set of parameters, semistructured interviews with stakeholders from Greece were conducted. The prior knowledge regarding the potential criteria was utilized to formulate six subjects for further discussion during the interviews, namely, sociodemographic characteristics, urban characteristics and land uses, transport infrastructure, parking facilities, and energy and environmental characteristics. In these fields, the interviewes had to search for potential spatial criteria.

To recruit the interviewees, our research team with the support of the Hellenic Ministry of Environment and Energy (HMEE) sent an invitation to a selection of key representatives, all of them with a thorough understanding of the transport infrastructure investment agenda from municipalities and local authorities, ministries, public bodies, associations, technical and working groups and independent experts related to urban planning, transport, and energy sector. Around 45 research engagement invitations were sent to a list of key stakeholders that were identified by us from the HMEE list of contacts. In total, 12 experts were interviewed. The main strategy for determining the final sample was to include a diverse spectrum of views and insights so that our results will not be one-sided but capable of illustrating a variety of different stakeholder perspectives from different areas with different priorities, values, and philosophies. From the public sector, four policy-makers

coming from the Ministry of Environment and Energy, the Ministry of Infrastructure and Transport, the Metropolitan Region of Attica, and the Municipality of Trikala expressed their views. The sample also included three market experts representing the associations of taxi drivers, gas station and parking facilities owners. In addition, one transport planner and three urban and regional planners with relevant experience on the topic were also interviewed. A representative of people with disabilities living in Greek cities was also included, as their possible concerns regarding the establishment of EVCSs on sidewalks had to be voiced accurately. The average semistructured interview duration was about 65 min. Interviews took place between October and November 2020.

A methodical thematic analysis was used to contextualize the data in accordance with some of the techniques and systematic analytic principles used in the authors' previous work [81–84]. The difference here was that the themes were already specified by the literature review to an extent and we had to uncover their different dimensions and expressions; thus, this was more of an analyst- or theory-driven thematic analysis and not a primarily data-driven one when themes were devised more spontaneously. Our analysis seeks to develop a fluid and recursive frame which is somewhat different from the rigid and structured frame that the traditional codebook approach uses. When writing up, our key aim was to provide "a concise, coherent, logical, non-repetitive, and interesting account of the story the data tell" [85] and to demonstrate the importance of the themes underpinning the choice of location for EVCSs by selecting the most characteristic, vivid and convincing individual raw responses so that we reduce bias.

In the sociodemographic characteristics, most of the interviewees mentioned the annual income of households as a potential parameter mainly due to the relatively high purchase cost of EVs today. They were of the opinion that local authorities should provide some incentives to citizens with lower incomes for buying an EV. The establishment of an EVCS in the public space next to their residencies can be considered as one of those. On the contrary, the creation of such facilities only in areas with high-income citizens is surely not a political decision that ensures social equity. Experts noticed that people with high income usually have a privately owned parking space in the ground level of their apartment buildings. Through buying an EV charger (i.e., wallbox), they will be able to charge their private vehicles at night hours. Due to the high population density appearing in Greek cities, the value of an apartment with parking space is high enough that middle-class citizens may not afford to purchase or rent. Therefore, they concluded that a measure that supports social equity is the establishment of EVCSs at districts with low share of households owning at least one private parking space.

Policy-maker A: "I do not think that it is allowed by the current Constitution to make distinctions based on socio-economic criteria as we speak about a public infrastructure. Surely in residential areas with high incomes the EVs will be more popular at least in the beginning. Yet, it is not a politically correct decision to locate charging stations in these areas only; we have to give some incentives to citizens with lower income."

Regarding the urban characteristics, most of the interviewees agreed that EVCSs should be established in locations with high concentration of workplaces. Such locations are, for instance, next to public services, next to education buildings, and next to healthcare centers or hospital. Large private companies were excluded from this category by most of the respondents, as they usually have enough private parking space to create EV charging points. Opposing views appeared regarding the significance of point of interest (POI), such as public squares, shopping (open) malls, and cultural centers in location suitability. These places usually exist in the city centers. Policy-makers mentioned that EV charging points next to POI will contribute to the attraction of more green trips in the central zones of a city and that is not a problem. On the contrary, planners believe that EVs may resolve problems related to air quality and noise; yet the problem of space in dense city centers will still exist. The views about land uses and EVCSs can be better illustrated in the following quotes:

Market expert A: "It is important to find the endpoints of daily vehicle trips; there is no reason to examine social groups. People from different income groups make daily trips from home to work. Urban areas with high concentration of workplaces will attract EV trips; therefore, it is a smart choice to add EV charging stations there."

Policy-maker B: "The city centers are the places where we should give incentives because we promised as mayors to provide public parking spaces for EVs at the points of interest each city has. I would prefer high concentration of EV charging stations in the city centers than in the residential districts outside of them. It is a policy to change the ratio of electrical vehicles over conventional vehicles that circulate in a city and therefore to reduce CO2 emissions and traffic noise."

Planner A: "We have to consider the plans that have recently developed in some cities regarding pedestrian areas around the points of interest. There are municipalities that have decided to protect the city centers from traffic. Therefore, the accessibility of an EV to a point of interest must be examined beforehand. I do not think that EV charging stations are necessary in the centers of cities, which already have an efficient public transport system or cycling infrastructure."

All the interviewees argued that EVCSs should be established in trip attraction, and not in trip production, locations. Transport hubs, such as railway or metro stations are the perfect locations for the creation of such facilities according to them. In our interviewees' minds, electromobility and multimodality can cooperate in creating a sustainable urban transport system. Transport hubs can be considered as an intermediate stop of a multimodal trip using sustainable transport modes. A planner has to study in detail the transport system of each city in defining these intermediate stops of trips. Congestion at EVCSs was not mentioned by the interviewees, as the penetration rate of EVs is very low at this moment in Greece and electromobility infrastructure planning and design strategies are still in their infancy stage. For now, and for the foreseeable future, our interviewees believe that the charging demand will not exceed supply and that congestion is not a decisive barrier. Last, those interviewees with a planning background suggested that some road links must be excluded from the analysis. Specifically, an EVCS cannot be established in the primary road network as there are no legal (on-street) parking spaces. Furthermore, links with very small width, without parking spaces or within pedestrian areas are not suitable at all.

Planner B: "The EV charging system of a city should encourage users to make multimodal trips on a daily basis. Multimodality means that somebody can leave his/her EV for charging and continue his/her trip with another electric transport mode, like an electric bike or an electric bus. I consider multimodality as a planning philosophy."

Streets with marked or controlled parking spaces should be preferred over streets with on-street parking according to the interviewees. Nonetheless, there is a debate regarding the necessity to create public parking facilities for EVs. A municipality can utilize a parking facility that already exists for this purpose. However, the proximity of these facilities to the previously mentioned land uses should be examined beforehand. Regarding electrical energy network, few interviewees had the expertise to point out one significant criterion. As a solution, most of them recommended a feasibility analysis after the definition of a list of potential locations derived from other criteria.

Policy-maker C: "There are residential areas that suffer from the fact that parking demand exceeds supply. By creating an EV charging space, you decrease the parking supply for conventional vehicles. There will be conflicts. There are already many complaints about the parking control systems established in some cities. Imagine now if you insert EV chargers in the parking management strategies, the problem will be much more complicated. I prefer EV charging points at already existing parking facilities."

Planner C: *"There are a few parking facilities with a limited number of parking spaces in Greek cities. Let us be honest, I do not think that municipalities will be able to create*

enough public parking facilities to meet the demand of EVs in the future. It is a utopia. So, I recommend turning the focus on urban streets, where vehicle parking is not prohibited today. Already marked or controlled parking spaces are potential spots to locate an EV charger."

In the list of suitable locations for EVCSs, historical city centers, and areas around archaeological sites cannot be included according to planners. Moreover, we should take into account the flooding risk before concluding that a location is suitable for an EVCS. Based on the findings of qualitative research, we finally develop a list of selected parameters that are presented in Table 3. This list is combined with exclusion criteria that are given in Table 4.

Criteria	Category	Units	Scoring Method	
Population density	land uses proximity	inh./he	Min-Max Normalization	
Walking distance from the nearest public administration building	land uses proximity; public services	meters	Global Scale	
Walking distance from the nearest hospital or healthcare center	land uses proximity; public services	meters	Global Scale	
Walking distance from the nearest school or university	land uses proximity; public services	meters	Global Scale	
Walking distance from the nearest recreation and entertainment point of interest (i.e. public space, shopping malls, cultural centers, etc.)	land uses proximity	meters	Global Scale	
Walking distance from the nearest transport hub/station (i.e., metro, railway stations, airports, and ports)	transport system and parking facilities	meters	Global Scale	
Density of marked or controlled parking spaces	transport system and parking facilities	space/100 m	Global Scale	
Share of households without privately parking space	transport system and parking facilities	%	Global Scale considering relevant statistics existing in each country	

Table 3. List of selected criteria.

Table 4. List of exclusion criteria.

Criteria	Category
Road link with high flooding risk	environment
Road link near an archaeological site or historical city centers	environment
Road link in the primary road network according to OSM	transport system and parking facilities
Road link within a car-free or pedestrian area	transport system and parking facilities
Road link with very low width	transport system and parking facilities
Road link without legal parking spaces	transport system and parking facilities

3.3. Development of Scoring Rubrics

At this step, it was necessary to develop linear scales to transform the quantitative data into scores ranging from 0 to 10. The description of scores has been given in Table 2; therefore, the selected levels per criterion should correspond with the description of each scoring level. Otherwise, the developed scale of location suitability index will have no meaning. The scoring rubric per parameter is indicated in Table 5. A Global Scale is used in 6 out of 7 parameters. In population density, a min-max normalization is preferred. To do

so, the population density of each city district is considered; the district with the maximum density gets the highest score (i.e., 10/10). Therefore, this parameter tends to establish EVCSs in areas, where a significant body of residents are concentrated.

Score	Population Density Per Zone	Walking Distance from the Nearest Point of Attraction	Share of Households without Parking Space	Density of Marked or Controlled Parking Spaces
0	min	$F(d_{walk}) < 45\%$	\leqslant 5% of households	0 spaces per 100 m
1		$F(d_{walk}) \ge 45\%$	$\leqslant 15\%$ of households	≤ 2 spaces per 100 m
2		$F(d_{walk}) \ge 50\%$	\leqslant 25% of households	≤ 4 spaces per 100 m
3		$F(d_{walk}) \ge 55\%$	\leqslant 35% of households	≤ 6 spaces per 100 m
4		$F(d_{walk}) \ge 60\%$	\leqslant 45% of households	≪8 spaces per 100 m
5	0.5 * (min + max)	$F(d_{walk}) \ge 65\%$	$\leqslant 55\%$ of households	≤10 spaces per 100 m
6		$F(d_{walk}) \ge 70\%$	\leqslant 65% of households	≤ 12 spaces per 100 m
7		$F(d_{walk}) \ge 75\%$	\leqslant 75% of households	≤ 14 spaces per 100 m
8		$F(d_{walk}) \ge 80\%$	\leqslant 85% of households	≤16 spaces per 100 m
9		$F(d_{walk}) \ge 85\%$	\leqslant 95% of households	≤ 18 spaces per 100 m
10	max	$F(d_{walk}) \ge 90\%$	>95% of households	>18 spaces per 100 m

Table 5. Scoring rubrics.

Regarding the parameters that describe the proximity of a link to the selected land use, the network distance is preferred over the Euclidean distance. The Euclidean distance is always equal to or lower than the network distance; in cities with rugged terrain, the difference between these two distances can be considerably high. To develop a linear scale from 0 to 10, this methodological approach takes into account the willingness of people to walk a distance in order to reach their destination from the EVCS. This probability can be described adequately by the so-called distance decay effect. As previous studies have pointed out [86,87], the distance decay effect follows an exponential function (a nonlinear function), while the mean distance of walking trips is approximately between 400 and 700 m. A link gets the highest score, when the 90% of road users are willing to walk the distance from the link centroid to the corresponding land use (i.e., transport hub, public administration building, point of interest). Therefore, the distance decay function is imported in the analysis in order to transform the probabilities into network distances.

In Greek municipalities, approximately 66% of households do not have a private parking space near their residences. To create a linear scale, we firstly estimated these percentages in all municipalities of Greece; afterwards, a histogram was plotted (see Figure 1). The maximum share of households without private parking space is equal to 99%, while the minimum is equal to 18%. Yet, concerning the data, we identified areas in some cities, in which approximately all the households had a parking space. Therefore, a district gets the score 0, when the share of households without parking space is lower than 5%. High suitability scores, i.e., 8, 9, and 10, are given in districts, where the residents do not have the required space to create their own charging point.

The length of a parking space is approximately equal to 5.5 m. In an urban road with on-street parking on both sides, the parking density cannot exceed 32 spaces per 100 m. In the last calculation, we included a buffer zone of 5 m in intersections; vehicle parking is prohibited in this buffer zone according to the existing traffic rules. Besides this is a common practice in many countries. The minimum density is equal to 0 controlled or marked positions per 100 m. The last case is quite common in Greek streets. Considering the above, a linear scale is developed; it starts from 0 spaces per 100 m (score equals to 0) and ends to more than 18 spaces per 100 m (score equals to 10).



Figure 1. Histogram of share of households without privately owned parking space considering all Greek municipalities.

In the exclusion criteria, a street is characterized as too narrow to locate an EVCS, if its width is equal to 9.5 m in one-directional roads and 11.5 m in two-directional roads. In the previous estimation, we take into account that the minimum width of a sidewalk with street furniture is equal to 2.1 m, while the minimum width of a parking lane is equal to 2.2 m according to the Greek guidelines. Last, the developed methodology does not recommend specific Euclidean distances in the criteria related to flooding risk and proximity to archaeological sites or historical city centers. The planner is responsible for creating buffer zones around areas by examining the spatial characteristics each city has.

3.4. Analytical Hierarchy Process

In this study, AHP is utilized to estimate the magnitudes of the selected criteria. AHP is a popular, readily understood, and easily implemented method [88] that was first developed in the 70s by Tomas Saaty [89]. Since then, several modifications and improvements of this method have been applied in a wide range of decision-making processes, especially in cases of complex transport policy problems, see, e.g., in [90–92].

AHP attempts to organize tangible and intangible factors in a systematic way [93]. In this method, the various elements of a problem are represented in hierarchical form and involves three fundamental steps: (a) decomposition, or the construction of the hierarchy; (b) comparative judgments, or defining and executing data collection to obtain pairwise comparative data on elements of the hierarchical structure; and (c) synthesis of priorities, or construction of an overall priority rating [94,95]. Therefore, the relationships between parameters and evaluation indexes can be examined using AHP, as it converts individual preferences into ratio-scale weights [88,96]. The selected criteria can be both quantitative and qualitative. Hence, AHP can provide a comprehensive view that can reduce potential hindrances in the decision-making processes, e.g., the selection of the best locations in the urban core to establish EV charging points.

Taking the first fundamental step of AHP, the selected criteria presented in Table 3 are organized in a hierarchical structure, which is presented in Figure 2. The developed hierarchy consists of three levels in total. In the first level, the criteria are divided into two main categories: urban planning and proximity to land uses and transport infrastructure and parking facilities. This distinction is connected with the dilemma about whether EVCS can be considered as part of the urban transport network or as a simple service point connected with particular land uses. The second level contains the majority of the selected criteria except one, i.e., the public services, that can be distinguished in three main categories appearing in the third levely: administration, public health, and education. Using this hierarchical structure, 10 pairwise comparisons are exported. More specifically, the upper level contains one main comparison. In the second level, the experts will be



asked to choose the best criterion six times, i.e., three pairwise comparisons per branch. Last, the third level introduces three additional comparisons in the assessment process.

Figure 2. Hierarchical structure of selected criteria.

In each of the 10 pairwise comparisons, the experts must choose the best criterion and to judge how much more important is the chosen criterion compared to the other one in a judgment scale from 1: equal importance to 9: extreme importance. To develop the assessment form, an open-source, web-based, online system called AHP-OS, developed by Goepel [97], was utilized. Through introducing the developed hierarchy, it automatically generates the resulting pairwise comparisons. Furthermore, it estimates the criteria weights using the AHP eigenvector method and the consistency ratio for each respondent. An answer is characterized as inconsistent when the consistency ratio exceeds 10% [97]. Yet, when the number of selected criteria is higher than 7, the existence of inconsistencies in the responses of individuals is reasonable [95]. By default, AHP-OS asks the respondent to reconsider his/her choices at the end of the assessment process in order to improve his/her consistency ratio. This option was used in this study, while a threshold equal to 20% was selected in order to decide whether the consistent of a response is acceptable or not. Last, the online tool provides the option to use a variety of scale functions to describe the ratings of individuals, i.e., linear scale, logarithmic scale, and inverse linear scale. In this study, only the classic linear scale was applied to estimate the final weights.

4. Results

The 12 stakeholders who expressed their opinions in the interviews filled the assessment form in the second stage of this data collection process. Each of them made 10 comparisons; thus, 120 comparisons were collected. Responses with consistency rate higher than 20% were excluded from the analysis as inconsistent; there were three inconsistent responses. Therefore, the final sample contained responses from nine stakeholders. In the closing set of responses, the minimum consistency ratio is equal to 3.85%, while the maximum ratio is 19.07%. Higher inconsistencies are observed in the third hierarchical level in which respondents were asked to choose the most important type of public service, i.e., public administration vs. hospital or healthcare center vs school or university. In this level, the group consensus is low, i.e., 42.6%, while in the second hierarchical levels, the group consensus exceeds 65%. The lowest group consensus is observed in the first level, i.e., 19.4%.

In Level 1, the factor of transport infrastructure and parking facility can be correctly characterized as the dominant one with a weight equal to 0.6224. Regarding the land uses, the proximity to POI seems to be the most important parameter with a percentage that is equal to 56.10%. Only two respondents chose population density as the most important parameter of the first branch. Considering the transport system, the experts decided that EV charging stations should be located in road links with marked or controlled parking spaces and in close distance to transport hubs. The weights of the aforementioned criteria are equal to 0.4463 and 0.4149, respectively. Different views are observed in the third hierarchical level; that is why all the selected parameters seem to be equally important. The parameter related to the proximity to hospital or healthcare center is the most significant with a proportion of 43.22%.

The final set of weights can be determined by multiplying the weights of the higher hierarchical parameters with the lower hierarchical parameters. The results of these multiplications are presented analytically in Table 6.

Table	6.	Final	set of	weights.
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Criteria	Spatial Parameters	Weights
Population density	dn	0.1168
Walking distance from the nearest public administration building	adm	0.0145
Walking distance from the nearest hospital or healthcare center	hlth	0.0207
Walking distance from the nearest school or university	edu	0.0127
Walking distance from the nearest recreation and entertainment point of interest (i.e., public space, shopping malls, cultural centers, etc.)	poi	0.2107
Walking distance from the nearest transport hub/station (i.e., metro, railway stations, airports, and ports)	hub	0.2591
Density of marked or controlled parking spaces	pk	0.2787
Share of households without privately parking space	priv	0.0865

The location suitability index is estimated as a weighted arithmetic mean of all the selected criteria. Using the developed scoring rubrics, the values of the spatial parameters are converted into a scale starting from 0 and reaching 10. As it has been mentioned, this scale describes the suitability of a link to locate an EVCSs. The spatial model function of location suitability is given by the following formula:

 $location\ suitability = 0.1168*dn + 0.0145*adm + 0.0207*hlth +$

$$+ 0.0127 * edu + 0.2107 * poi + 0.2591 * hub + 0.2787 * pk + 0.0865 * priv$$
(1)

5. Discussion and Conclusions

Transport can be both the cause and resolution of societal inequalities [98]. Travel demand measures on their own are not enough to guarantee the former so carrots should be also intensively and systematically promoted and implemented in a people-centric, yet sustainable and resource-effective, way [99]. As the diffusion of EVs is an important aspect of government policy in generating a transition to a low-carbon mobility [100], and the anticipated commercialization of the EV technology will necessitate changes and investments in optimal charging infrastructure [101], providing a framework for identifying optimal location-making for EVCSs is a critical issue for sustainable energy and transport policy.

The purpose of the current research was to identify the main factors affecting the suitability for establishing EV public charging points, and then formulate a compact method for the deployment of these stations in the road network. The process of locating

EVCSs is significant, as it influences the effectiveness and the functionality of the entire electromobility eco-system. In this context, the suggested method can greatly contribute to existing transport systems especially in countries with no prior EV public charging network system such as Greece. It is a preliminary way to establish an EV culture, and pave the way towards the future, where EVCSs would become mainstream, well spread, and fairly distributed across a city. This research may also have the potential to assist, to some degree, countries with similar socio-economic and transport readiness characteristics with Greece that favor electromobility investments but are "starting from scratch". Thus, the research might have value beyond the Greek context.

Through a qualitative approach, combining interviews and AHP, this paper identifies and systematizes the main criteria which determine the suitability of road network links. Specifically, these criteria derived from a thorough literature review (mainly papers published after 2010) and semistructured interviews thematically analyzed. These interviews proved to be useful since they revealed a diverse spectrum of thoughts and dilemmas that stakeholders shared. In general, we found evidence that the selected set of interviewees have different perspectives on the issue. The inclusion of different perspectives was one of the objectives of this study and helps us understand the diversity and variety of options, choices, and visions between key stakeholders. Consequently, the group consensus is not very high; considerable contradictions that do emerge in some specific issues. These differences might reflect the historic and still ongoing controversy between land uses and transport activities. To be more specific, policy-makers suggested that EVCSs should be mainly deployed at POI, whereas planners argue that areas friendly to active mobility such as pedestrianized streets, squares, etc., should be protected. Nonetheless, there is a high level of agreement in the case of transport hubs (train, metro, airport, and ports) and the conceptualization of EVs as a mode primarily supporting multimodal travel. Furthermore, some participants stated that constructing public parking stations is quite difficult in Greece, therefore road segments have to be prioritized.

The above mix method process resulted in the recognition of two categories: (i) land use proximity and (ii) transport system and parking facilities; eight criteria were also identified. Beginning with the land uses category, the parameter of population density which is found in many related studies [35,73,79] signifies the potential demand, thus ensuring the utility of the EVCSs. Moving to the rest parameters, we may encounter walking distance from the nearest public services, i.e., administration buildings, schools and healthcare. This set of parameters illustrates the need of the charging points to accommodate the employees and visitors of these places, integrating EVs even more into daily life. In the same context, the next parameter includes the walking distance from the nearest public space, shopping malls, cultural centers, which is a feature frequently encountered in the existing body of literature [59,73,79].

Focusing on the second category, the first parameter is the waking distance from the nearest transfer hub/station which enhances the notion of multimodality in our proposed method, and it is also found in other related studies [34,79]. Another feature taken into consideration is the share of households with privately owned positions/reserved parking seats, addressing social equity issues in the deployment of EVCSs [72]. Last, there is also a noteworthy parameter, encountered in published scientific works [34,73] that calculates the density of marked or controlled parking spaces. This parameter reflects the existing regulations about parking policy and could be a key input for establishing EVCSs.

In the final formula, we excluded income from major factors as the proposed plan should ensure equity to all users and not prioritize them according to their economic position or status. This is a result coming out from the interviews, where many stakeholders noticed that income might create inequalities and conflicts. Actually, this is a finding that seems to be puzzling the existing body of literature, with some papers proposing it [43] and others denying its integration [41,72]. Finally, it should be noted that the serious lack of EVs in Greece is portrayed in the expressed views of stakeholders. EVs still pose an ambiguous entrant to Greece's urban planning ethos where limitations and potential are not yet fully discussed and thus recognized.

The second pillar of the research is the use of the AHP method, which gives weights to the parameters based on the opinions of several experts. The controversy between land use and transport is prominent in this step as well. This means that AHP tries to diverge these two different approaches. According to this process, the most considerable factors are (a) marked or controlled parking spaces, (b) transport hubs, and (c) points of interest. On the contrary, those that are less significant are found to be the public services. Therefore, there is a clear preference of transport features over the land use ones (62% over 38%). This condition, which is discreetly shown in the final formula, is probably explained by the close conceptual relevance of EVCSs with parking facilities and regulations, and transport hubs, as electromobility is principally considered a transport characteristic. In the end, even stakeholders with a background stemming from urban studies, preferred the transport category over the land use one.

When looking into the outlined method, we shall mention that this multicriteria spatial approach is in congruence with previous works such as Costa et al. [79], Erbas et al. [35], and Efthymiou et al. [73]. The main focus is on the trip attraction (terminal points) rather than on the trip production (starting points). This rationale was evident in the semistructured interviews and agrees with the current literature [45]. Furthermore, we paid particular attention to the already existing transport system and not in future infrastructure. Nonetheless, this constraint might be changed in future research attempts. Discussing utility, we may argue that the method we formulated could be a useful tool for tackling range anxiety, which is a crucial factor for adopting EVs. The method meets today's needs where public charging points are still few, both in public roads and in private residences. Last, a great asset of the proposed method is that it can be easily applied, as all the steps are distinct and sufficiently described.

Due to its nature, the current study implies considerable practical recommendations. First and foremost, the suggested method could be utilized by policy-makers and stakeholders, particularly as part of an integrated electric mobility strategy. Therefore, it could function as a decision-making tool along with other incentives promoting EVs. For instance, in Greece, 254 municipalities are funded by the Green Fund (a public law entity reporting to the Ministry of Environment and Energy) to implement their Electric Vehicle Charging Plans (EVCPs) and there is a prediction for at least one charging point per 1000 residents.

Focusing on limitations, we did not consider the deployment of EVCSs, as a network problem. As a result, there is no coverage indicator set as a variable in the suggested method. On the contrary, we scrutinized this deployment problem as a phenomenon with broader dynamics in space, studying the area in a holistic view and not necessarily limited in some candidate points. An odd, but at the same time, substantial characteristic of the developed method is that it estimates link suitability, thus ensuring great flexibility and giving the policy makers the potential for reaching the final decision not always in urgency. Tellingly, this particular characteristic entails a spatial approach that is significantly different from other similar studies using GIS tools that preceded our work.

Additionally, our analysis did not deal with congestion issues at EVCSs [62]. Definitely, long queues at EVCSs will be an important transport problem, which may affect the efficiency and the sustainable character of the urban transport system [102]. It is expected to emerge as a potential problem in the long term when the penetration rate of EVs will increase. Yet, this study focuses exclusively on the establishment of the first charging points that will help with the increase of the number of EVs circulating in the city. For now, and for the foreseeable future for the Greek context at least, EVCS traffic alleviation is not a critical issue and not something that has been underlined by our interviewees. The plans reported in this work should be updated in the future considering the new challenges that may arise from the significantly increased use of EVs (i.e., feedback loops).

Furthermore, the applicability of the proposed method is greatly connected with spatial data availability. More specifically, in agreement with a general trend both in scien-

tific and professional works, we tried to develop a method that utilizes open-source data, in order to ensure an easy and seamless application. However, this was not fully possible, thus leaving some parameters unclarified. To tackle this drawback, we suggest that new scientific studies or projects incorporating this method should use their corresponding data (e.g., statistical authorities). Another limitation is that the AHP process is difficult for stakeholders to understand due to lack of familiarity. A minority of them had already relevant experience. This undoubtedly had an impact on the results, but we managed to limit the side effects, by declaring the main points of the process and assisting the participants. Last, the current paper did not validate the proposed spatial model function, and that is a task that could be accomplished in the near future. The value of a case study would be extremely helpful towards the validation and improvement (if it is necessary) of the suggested method. In addition, case studies will show how this method adjusts to various countries where planning procedure is different.

It is reasonable that electromobility and EVCSs cannot be fully analyzed in a single paper, and for that reason, further research is necessary. In this context, we propose future research to examine the way our method will influence actual planning procedures. Therefore, an ex-ante evaluation will reveal and ratify the utility of our method or expose unpredicted shortcomings. Finally, we suggest future studies to utilize new methods, preferably mixed-based, including spatial analysis and optimization techniques, aiming to achieve better and more efficient results.

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