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What is the problem? The obstacles to the electrification of urban mobility in Mediterranean cities. Case study of Valencia, Spain

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ABSTRACT

The transport sector is answerable for around a quarter of the global CO_2 emissions sent into the atmosphere, and 50% of the greenhouse gases in the cities. Considering a staggered introduction of renewable sources in the electricity mix, the introduction of electric vehicles (EVs) in the urban transport network arises as a necessary environmental solution. However, their integration is facing a wide range of barriers, many of them only qualitatively known, or uncertain. This paper presents a multicriteria methodology to assess such obstacles to the electrification of urban transport of Mediterranean flat medium cities. This analysis considers context analysis, literature review, and the application of the Multi Criteria Decision Making Method: Analytic Network Process, with the aid of a panel of experts representing quadruple helix involvement (Government, Business, Society and Academia). As a case study, the city of Valencia (Spain) was chosen, which has been in a deep transition of mobility in recent decades. Results revealed that the most influential barriers turned out to be the insufficient subsidies for EVs' development, the battery autonomy power and the CapEx of batteries. Moreover, private passenger transport followed by freight transport ranked as the most affected urban transport alternatives.

1. Introduction

Climate change is one of the most critical global issues, mainly motivated by the excessive amounts of Greenhouse Gases (GHG) sent into the atmosphere [1]. In this regard, transport turns out to be one of the most polluting activity sectors, being answerable for around 25% of the global CO_2 emissions, and around 50% of the cities' GHG emissions [2]. Besides, almost 93% of the global transport consumption in 2017 derived from oil products, whose reserves are limited in nature [3]. Both circumstances, fossil emissions and finite oil reserves, have boosted the interest and need for electrifying the transport sector [4,5]. Numerous studies state the necessity of accompanying this electrification with renewable generation [6]. So, the balance between the GHG emissions produced by the increase of electricity demand of electric vehicles (EVs) compared with the emissions avoided by their use is clearly beneficial, making EVs an environmental solution [7–9].

Despite the urgency of achieving sustainable transport and the environmental suitability of EVs, their acceptance and penetration in urban transport are facing some constraints [10]. For instance, the European Union (EU) set the target of achieving emission-free urban passenger transport by 2050 [11], aiming for a wide introduction of private EVs. Nevertheless, the average market share of electric passenger cars in the EU in 2017 barely reached 1.14% [12]. On the one hand, Sweden topped this list (5.28%), followed by Belgium (2.68%), Finland (2.57%), Netherlands (2.20%), and Austria (2.06%). On the other hand, the five countries from the EU with the lowest data were Czech Republic (0.23%), Greece (0.22%), Poland (0.21%), Estonia (0.2%), and finally Croatia (0.05%).

Different researchers tried to shed light on this issue: the barriers that EVs are facing to penetrate in the transport system. Goel et al. established 12 barriers to the introduction of EVs grouped into 4 different clusters: technical, policy (institutional), infrastructure, and market, being this last one composed in turn by economic, environmental, and social obstacles [13]. Haddadian et al. divided social and economic obstacles included by Goel et al. in the market group as two different clusters [14]. M.E. Biresselioglu et al. identified different obstacles and motivators to the introduction of EVs according to the social unit: formal, collective, or individual [11]. Zurbaryeva et al. used AHP to try to identify lead markets for EVs development in Europe in 2012 [15]. They concluded that there were several success factors that could predict a relevant development of electric mobility in regions such as the Mediterranean, which has not happened. These results reveal that a

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broad range of difficulties and barriers influence the penetration of EVs in the transport sector. Some of them may seem to be the expected main drivers, like the high selling price of these vehicles [16], while others are sometimes ignored despite their significance, like the users' willingness to accept driving pattern changes [17].

Despite all this research, the way these obstacles influence the electrification of different urban transport alternatives remains unclear; especially, how trade-offs among different targets in conflict happen and how the different actors of the systemic change struggle with them [18, 19]. These barriers can be grouped in different clusters, although with interdependences among them as well as with the different transport alternatives [13]. Evaluating these alternatives in an urban context based on their performance regarding multiple barriers arises as a multifaceted problem that demands a Multi Criteria Decision Making Method (MCDM). Different studies have proven the suitability of MCDM to evaluate difficulties while introducing non-conventional vehicles in the transport system. Raj et al. used Grey-DEMATEL MCDM technique to analyze the barriers to the adoption of autonomous vehicles [20]. M.-H. Sehatpour et al. prioritized the most suitable alternative fuels for light-duty vehicles considering economic, technical, social, and political aspects using PROMETHEE MCDM for the Iran case study [21]. Focusing on EVs, a few papers have investigated consumer attitudes towards the introduction of such vehicles. Hence, N. Sousa et al. applied the MCDM ELECTRE TRI to estimate consumer acceptance of vehicles with alternative powertrain technologies, i.e. hybrid, plug-in, and battery EVs [22]. Duarte G. et al. developed a multicriteria decision analysis-based questionnaire to revise consumer preferences for EVs in Portugal [23]. These MCDM methods require complete, quantitative, and correct information. Nonetheless, some obstacles to the electrification of urban transport, especially social and institutional ones, do not match with these requirements.

In this context, specific MCDM such as the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) manage such scenarios of incomplete, qualitative, and/or uncertain information [24]. Both MCDM allocate resources according to ratio-scale preferences. Ratio-scale evaluations enable prioritizations based on trade-offs [25]. Regarding AHP, some authors used this method to investigate difficulties to EVs introduction. Stefano de Luca et al. used the method to study the different factors that may affect users' willingness to purchase EVs [26]. Ma et al. compared the similarities and differences of new energy vehicle policies (including EVs) with traditional vehicles' ones through AHP to enhance the development of the first ones in China, Japan, Germany, and the United States [27]. However, AHP's main drawback lies in the necessity of setting independent criteria to model the reality. But this is not the case for social, technical, environmental, institutional, or economic obstacles, which present interdependencies among them regarding the electrification of urban transport. Thus, AHP models are an important simplification of reality.

ANP overcomes this disadvantage and enables mutually dependent inter-relationships among factors at diverse levels. For this purpose, ANP models the prioritization problem as a network of criteria and alternatives arranged into clusters [25]. This provides precise modeling of reality, where all alternatives and criteria can be related to each other. Due to this characteristic, researchers and policymakers use ANP to analyze complex problems in energy systems [25,28], such as the introduction of EVs in urban transport. Tworek applied the method to validate the new concept of electric transport [29]. C. Li et al. evaluated policies to promote clean energy vehicles (including EVs) in China using ANP [30]. Wu Y. et al. analyzed the best location of EV charging stations using ANP to enhance EVs' acceptance among users [31], while M. Husinec et al. focused this study on electric freight transport [32]. None of these studies addresses the obstacles to the introduction of EVs and their affection to the different transport modalities, where a research gap emerges. Moreover, their application to urban contexts remains unexplored.

This paper tries to fill in such gap by providing an appropriate methodology to evaluate the obstacles to the electrification of urban transport areas, and how these barriers influence the different transport alternatives. This method incorporates context analysis, literature review, and the application of ANP with the aid of a panel of experts. The experts have been selected following the model of the European Innovation Partnerships (EIPs) as a tool for systemic change [33]. In this way, the obtained expert knowledge involves the quadruple helix: Government, Business, Society, and Academia [34]. This selection reflects the multicriteria approach of the analyzed issue for urban contexts since the mobility challenge to overcome could only take place if these four groups synchronize together. Academia researchers analyze the problem arisen and identify methodologies to solve it [7]. Private sector professionals are essential to materialize researchers' outcomes into suitable products for the society regarding electric mobility [35]. Public policymakers have the power to promote policies to enhance transport sustainability and apply the proposed solutions [16]. Finally, users are the key stakeholders in the transition of transport towards sustainability, since they benefit and have the right to mobility [36]. Moreover, they provide feedback to the other stakeholders on the application of measures, developed products etc.

This quadruple helix involvement has been used in previous research to address sustainability strategies for cities. Selada applied the quadruple helix to analyze their collaborative dynamics to develop smart cities, taking the city of Arena (Portugal) as the case study [37]. De Sousa assessed living laboratories' contributions to smart cities from a quadruple-helix perspective, with three urban cases: Living Lab Florianópolis, Living Lab Itaipu Technological Park and Porto Digital [38]. Suárez and Gibaja focused on the performance of Quadruple Helix to compare energy transition initiatives between cities in Germany and The Netherlands [39]. Although quadruple helix studies were developed for different urban issues, none of the previous research tackled the obstacles to EVs and their affection to the different transport alternatives in an urban context, being this application, a novelty presented in our paper.

For the methodology, a participatory approach is proposed as the complexity of the barriers is sure to be subject to uncertainty and diversity of preferences. Multi expert participation in such activities is crucial for selecting the relevant indicators and discussing the discrepancies [40]. In participatory decision-making procedures based on Analytic Network Process (ANP), the quality of experts is more important than the quantity [41,42]. Ferwati et al. affirm that ANP does not need a big panel size [43]. In fact, after a careful review of the literature, this number was found to range from 2 to 20 experts, depending on the type of problem and the way the model was approached.

The presented methodology focuses on modeling a specific city pattern: a Mediterranean Flat Medium City (MFMC). Such a pattern includes all the cities with Mediterranean climatology, architecture, flat orography, medium size and a mature electricity distribution system. The selection of MFMC for the study lies in the suitability of such cities for the transition towards electric mobility. Firstly, their high levels of solar radiation could provide clean electricity for EVs, so that their environmental impact significantly decreases [7]. Second, MFMC present compact cities with short distances, which become ideal to match EVs batteries autonomy and recharging needs [44]. Later, flat orography of MFMC enables uniform demand for EVs batteries, without extra requirements [45]. Finally, their mature electricity distribution systems can cope with the introduction of EVs from the electricity perspective [46]. Table 1 presents studies that describe some problems to the development of EVs in specific Mediterranean cities. Nonetheless, none of them provides a complete assessment for the issue aroused (neither multicriteria ANP methodology nor Quadruple Helix Involvement) neither tackles the MFMC.

To prove the feasibility of the multicriteria method, it is applied to the Valencia case study. To the best of the authors knowledge, it is the first study of the described features applied to a MFMC city in Spain. Valencia is the capital city of the Comunidad Valenciana, a region located in the east of Spain, which meets all the MFMC features. This city

Table 1
Initial list of criteria and electric mobility alternatives.

Clusters	Barriers	Description	Research
Technical	Shortage of public recharging points	The quantity of public recharging points is not enough to ensure a feasible recharge for EVs users.	[11,50]
	Batteries' autonomy power	The driving time of EVs without recharging depends on the autonomy power of their batteries, which can be insufficient for long travel distances.	[17,51]
	Long time recharging periods	The time needed to recharge EVs depends on the recharging strategy used (slow, medium, fast or ultra-fast). Unlike power engine vehicles, this process is not immediate. Using the ultra-fast recharge, it might still take 20 min approximately to recharge.	[52,53]
	Negative impact on the electrical grid of non-scheduled recharge	The massive introduction of EVs in our societies may lead to an increase in the peak power demand unless a controlled recharge strategy is implemented to avoid it.	[54,55]
	Lack of standardization in EVs components	Most of the EVs' components (especially connectors and batteries) have been produced following different standards, which has led to noticeable difficulties in the recharging and repairing processes.	[14,56]
	CapEx of batteries	The capital expenditure of EVs batteries, which emerge as one of the main components of these vehicles, is still too high for their ordinary manufacturing.	[57,58]
Economic	CapEx of EVs	The capital expenditure of EVs is nowadays high compared to the average income of citizens. The limited offer of EVs models, together with the high cost of some EVs components and the novelty of the technology justify it.	[16,59]
	CapEx of recharging points' structures	The development of EVs needs the installation of new recharging structures, with the corresponding initial capital-intensity.	[60]
	OpEx of recharging points' structures	Cost associated with the day-to-day management and maintenance of the recharging installations.	[61]
Social	Fear of changing pre-established driving patterns	Driving internal combustion engines has been a key identity factor in Western culture. Sociologically, these patterns tend to lock in and make habit transition difficult.	[62,63]
	Lack of knowledge of electric mobility	The lack of information is a market failure, and knowledge regarding EVs and their potential benefits is uncommon among consumers, who do not have a clear idea about EVs costs and fuel costs savings, infrastructure, and incentives of EVs.	[64,65]
	Lack of previous EVs models	Consumers mistrust EVs due to the limited availability of models. Moreover, until now EVs have focused on narrow segments of consumers with limited designs.	[11,14]
Environmental	Life cycle of EVs batteries	The whole environmental assessment of EVs batteries (lithium-ion), from the extraction of the raw materials to the final production, reveals a high CO_2 footprint of these elements.	[66,67]
	Finite batteries resources	Most EVs batteries are lithium-ion ones, whose main components (lithium and cobalt) are present in nature as finite resources.	[68,69]
	Residues of EVs batteries	The residues provoked by EVs batteries (lithium-ion) cause a high level of pollution. Moreover, the recycling process of the batteries, which also pollutes a lot and complicated, recovers only 50% of the components.	[70,71]
Institutional	Insufficient subsidies for EVs development	Spain and other MFMC have a large car industry based on Internal Combustion Engines. This has led to subsidies to purchase this kind of car and leaving the promotion of EVs at a lower scale compared with other European countries.	[72,73]
	Insufficient traffic taxes to promote EVs	Private transport is key to most citizens that heavily depend on and use private cars. Due to this pattern, in Spain and other MFMC Diesel fuel has tax exemptions compared with other countries, making it more competitive. Moreover, tax exemptions to EVs are still not enough to make them competitive.	[59,74]
Alternatives	Mobility of services	Vehicles used by public services such as ambulance drivers, firefighters, and police to transport necessary material, goods or people. These vehicles normally run on short distances and un-plannable routes. Their recharge takes place in their base platform (hospitals, firefighter stations, police stations …) and they should always be ready since the services provided become critical.	[75,76]
	Freight transport	Transport used to move and deliver goods, commodities, and cargo inside urban areas. These vehicles normally run on long distances and plannable routes. Their recharge takes place in their base platform, although some of them can promptly also recharge at public stations.	[32,36]
	Private passenger transport	Transport alternative that enables the individual transportation of passengers that own a vehicle. These vehicles present a wide variability dynamic since they depend on users' necessities. They can run on long or short distances and plannable or un-plannable routes. Their recharge takes place both at private parking and public stations or recharging points	[8,77]
	Private transport sharing	Transport that individual travelers share either as a group or is facilitated by public organization, private companies or by their own interest. These vehicles run on short distances and un-plannable routes. Users do not need to worry about their recharge. When transport sharing depends on organizations, companies etc., recharge normally takes place in their base platform. However, when it depends on individual travelers, they normally recharge at private parking.	[78,79]
	Public passenger transport	Transport alternative that allows the collective transportation of passengers that have paid a tariff. These vehicles run on long distances and completely planned routes. Their recharge always takes place in their base platform.	[80,81]

is immersed in a deep transition towards sustainable mobility, including policies to reduce private transport, boost public transport, increase cycling and walking alternatives, and the introduction of EVs in the city, framed in the Electric Mobility Plan [47]. Hence, this paper aims to assist policymakers with identifying and overcoming barriers to the electrification of the urban Valencian transport sector. Moreover, our paper is the first one to approach this question with the above explained methodology.

To conclude, the challenge that the authors tried to overcome with this paper was to understand why electric mobility in MFMC, which present the most favorable features to face such transition, is evolving slowly. To achieve this aim, the authors analyzed the obstacles to EVs in MFMC and their affection to the different mobility alternatives with the next contributions:

- The multicriteria methodology ANP is used for the first time to assess the barriers to EV penetration in Mediterranean cities. ANP enables mutually dependent inter-relationships among factors at diverse levels, providing precise modeling of the reality of EVs obstacles affection to transport modalities, where all alternatives and criteria can be related to each other.
- The methodological approach is based on the quadruple helix expert knowledge and incorporates the involvement of: Government, Business, Society, and Academia. This selection reflects the

multicriteria approach of the analyzed issue for urban context and allows understanding of how barriers are seen and prioritized by different types of stakeholders.

- The application of the method contemplates MFMC as a whole, due to its suitable features to enable mobility transition. Specifically, Valencia was selected as MFMC case study, being the first Spanish case study for such kind of studies. This city is immersed in a deep transition towards sustainable mobility. Quadruple helix experts from Valencia shared their vast knowledge of the field.

The paper is organized as follows: section 2 describes the methodology, section 3 presents the application to the Valencian case study and section 4 provides the results and discussion of this study. Finally, the paper concludes in section 5.

2. Methodology

This section presents the methodology developed to assess the obstacles to the urban transport electrification of cities with a MFMC pattern. Such an analysis model covers all the cities with Mediterranean climatology, architecture, flat orography, medium-size, and mature electricity distribution. However, the model must be adapted to each specific city, as explained afterwards.

The method contemplates three different stages. The first one comprises a literature review and context analysis of the topic. Then, the second stage describes the selection of the panel of experts. Finally, the third phase presents the application of the ANP method. Fig. 1 presents the flowchart of the multicriteria methodology, including all the feedback loops with the experts along with all the procedures.

2.1. Literature review and context analysis

The aim of this stage consists of identifying all the barriers and transport alternatives that could be affected by such obstacles in the so-called MFMC. The climate, size and relief of cities significantly influence the demand for different types of transport, and the conditions under which they operate. The type of built-up environment (distributed or compact), the maturity of the electric grid and other local socio-economic factors also play a role in the choice of which transport to use and how. Therefore, the barriers to the penetration of urban electric mobility vary in different cities and this study has focused on the characteristics of MFMCs.

With this aim, a general literature review for a universal application was developed and adapted to cope with the necessities of MFMC [48, 49]. As a result, Table 1 presents a starting list of 5 different transport alternatives and 17 barriers, which are divided into five clusters: technical, economic, social, environmental, and institutional. For simplicity, it is assumed that the usage patterns of each type of transport do not change, but only adapt to the new requirements of electric mobility.

2.2. Expert knowledge

Once the problem's contextualization is set, the method requires the collaboration of a panel of experts to represent the possible different approaches to the research issue (Fig. 1). As introduced, due to the semi qualitative nature of the information to include in ANP, the quality of experts turns out to be significantly more important than the number of them, as numerous researches demonstrate [28,41,42]. Unlike research techniques based on surveys with large sample sizes, such as the one used in Ref. [82], ANP method focuses on expert knowledge, i.e. experts develop organizational mental structures that enable them to recognize a situation and effectively recall the most appropriate knowledge to solve a specific problem [83]. Hence, the expert selection process is of utmost importance, being backed by three main rules [25,84]. First, experts should be selected according to three features: broad experience on the issue, belong to a specific category of specialists on the problem, and willingness to apply the procedure. Second, the panel should be as inclusive and balanced as possible. Thirdly, ANP requires including more than one expert in each group, so that their opinions can be contrasted.

Considering this guideline, the literature review, and the authors' experience, the expert group comprised key stakeholders regarding the electrification of urban transport in MFMC throughout quadruple helix partnerships: academic researchers, private sector professionals, public policymakers, and users [85,86]. The panel of experts is as complete and balanced as could be arranged following the three rules. This way, the barriers to urban electric mobility are addressed from the different approaches to systemic innovation.

Based on the Innovation Helix approach, experts are classified based on their experience in the problem to be solved, their position as stakeholders, not their specific knowledge. However, the classification is not unique; each expert's cluster can cover one or more expert profile and vice versa. Thus, researchers whose investigations lead to suggesting policies to improve sustainability in the transport sector can take the role of policymakers. Another example lies in professionals from the private sector who share their experience in academic seminars as associate professors: they could be considered private sector professionals or academia researchers indistinctly. Finally, experts from academia, the private sector, or politics could be at the same time users of EVs. Hence, setting the panel of experts with these profiles according to the three rules requires a thorough analysis of the case study, discussed in section 3.2., and a careful assignation of roles in the application of ANP.

Finally, ANP converts the qualitative information provided by the expert panel into quantitative information. This usually masks possible biases arising from the fact that there may be more or fewer experts in each group. Therefore, the information should be shown in detail per expert, even when aggregated [41,42].

2.3. Analytic Network Process

The Analytic Network Process (ANP) is a methodology created by Saaty [24] that aims to help decision makers in complex scenarios with multiple criteria that are qualitative and with imperfect information. The different criteria are grouped into clusters that can all be interrelated in any possible way, providing modeling and comparisons among interdependent elements. The main processes of the method are the following [25]:

1. Identification of the elements of the network and their relationships.
2. Pairwise comparisons of both clusters and elements using Saaty's 1-to-9 scale.
3. Construction of the unweighted supermatrix, which represents the interrelationships of all elements in the network.
4. Construction of the weighted supermatrix, which considers the cluster comparison to weigh the elements.
5. Obtention of the limit supermatrix by raising the weighted matrix to limit powers until the matrix converges.
6. Obtention of the prioritizations of the elements given by the limit supermatrix.
7. Interpretation of the results.

The pairwise comparisons relate to the network elements' relative importance. The score of a_{ij} in the pairwise comparison matrix represents the relative importance of the element on row i over the element on column j, i.e., $a_{ij} = w_i/w_j$ where w_i is the weighting of the element (i). With n elements in the network, the comparison matrix (A) is defined as:

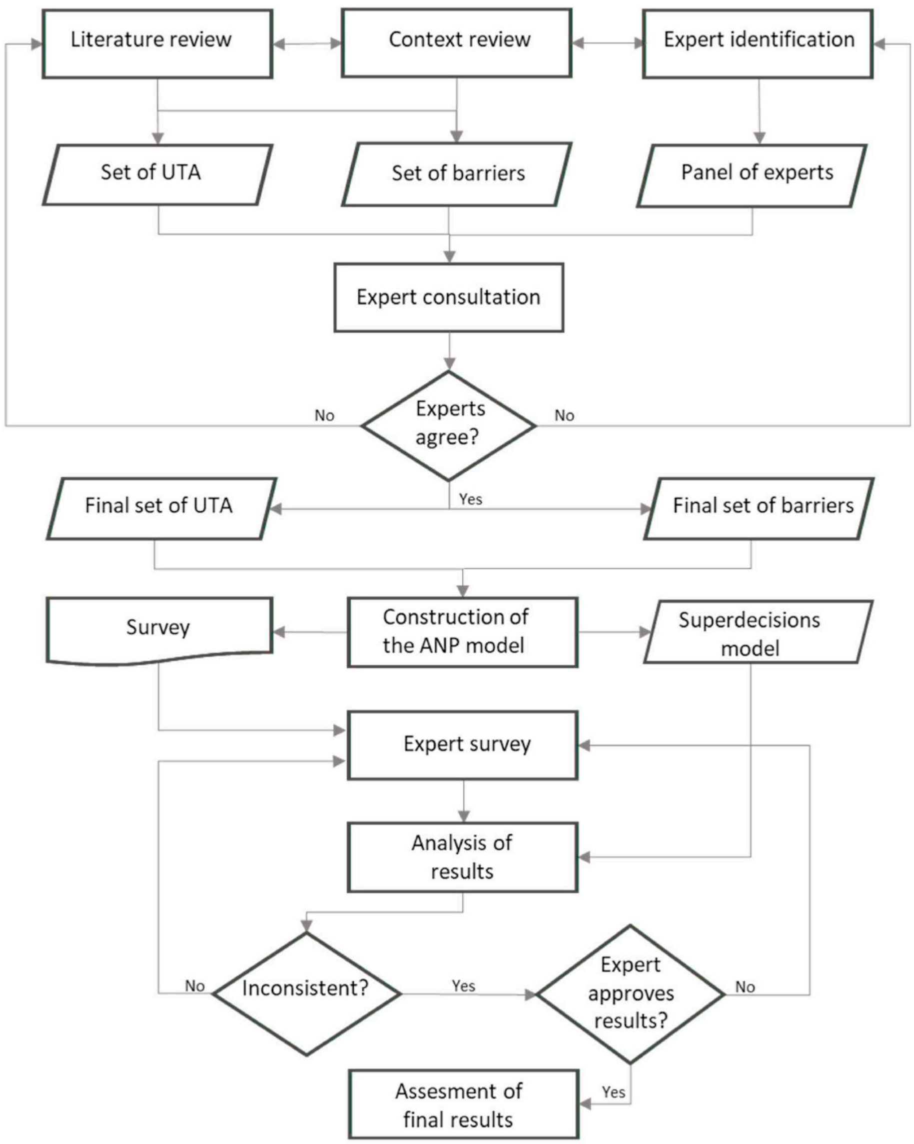

Fig. 1. Flowchart of the multicriteria methodology. UTA: urban transport alternatives.

$$A = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & & w_2/w_n \\ \vdots & & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

The relevance of each element of the network is a non-dimensional value. Based on the questions made in a questionnaire to feed the method, ANP weighs the influence of the barriers on the other barriers and on the transport alternatives.

The usage of the ANP in this work is related to the study of the electrification of transport in MFMC. This is a multicriteria decision issue, where interdependencies exist between barriers and technology alternatives. The assessment of the interrelationships of barriers and alternatives will help decision makers to set priorities in tackling barriers related to urban transport electrification, and also, to rank the order the types of transport based on their vulnerability to the barriers.

3. Case study

To prove the feasibility of the multicriteria methodology, we applied it to a specific case study: Valencia (Spain). Hence, this section presents the context of the selected MFMC, the profile of the ANP experts, the final barriers and transport alternatives considered for the study, and the obtained ANP model.

3.1. Valencia: an MFMC immersed in a sustainable mobility transition

Valencia is the capital city of the Comunidad Valenciana, a region in the east of Spain [87]. Its Mediterranean climatology is characterized by mild and rainy winters together with dry and hot summers [88]. Its coastal location provides the city with a flat orography, with a maximum height of 40 m in the inland outskirts [89]. The city population is close to 800.000 inhabitants. Moreover, its citizens enjoy a mature and reliable electricity distribution system. As a result, these four features allow Valencia to be fitted inside the MFMC pattern [50].

In general terms, Spain presents one of the lowest EVs penetration in Europe with only 5% and 3% of new cars in 2020, being hybrid and fully electric respectively [90]. Regarding the electricity production used in the city, the Spanish power system is characterized by decreasing trend in the grid's carbon intensity of 0.14 tCO_2eq/MWh in 2020 [91].

Daily, 2.3 million trips occur inside the city of Valencia. Of these ones, 46.7% of them are non motorized (foot or bike), 31.4% relate to private transport systems, 21.1% refer to transport in public buses, and the rest are related to metro or train trips. In that sense, most of the motorized transportation relates to private systems and public buses [92]. The average age of the public bus fleet is 7.3 years with 164 of them already being hybrid and 2 being totally electric [93]. Additionally, 363.262 private vehicles are registered in the city with an average age of 12.3 years [94]. Of these vehicles, 52% are gasoline, 47.6% are diesel, and only 0.1% are electric. Regarding, the rest of the types of vehicles, they exist 24,346 freight transport vehicles, 25,478 trucks, 1091 busses, and 2862 cataloged as “other”, which include police, ambulance, and firefighters trucks [95]. Finally, the GHG emissions associated with the city of Valencia, the transport sector represents over 50% of them. Therefore, being one of the main focuses of action.

Besides, the region is experiencing a steep sustainable mobility transition mainly boosted by the Electric Mobility Plan [47]. This Plan was introduced in 2017 by the Valencian Ministry of Sustainable Economy, Productive Sectors, Trade, and Work, together with the Valencian Institute for Business Development (IVACE). The plan establishes three scenarios of development (2020, 2025, and 2030) with two clear objectives: an incremental introduction of EVs and electrical recharge points in the region. Hence, the final 2030 goal is that EVs represent at least 25% of the market share together with creating one fast recharge point for every ten EVs. The final achievement of these requirements would lead to a remarkable GHG emissions reduction, estimated by the Plan in 622,000 tons per year of carbon dioxide reduction. And recently, the city established the European goal of becoming a Carbon Neutral city by 2030, signing an agreement and promoting a holistic sustainability plan for the city.

3.2. ANP experts’ profile

As previously discussed in section 2.2, the panel of experts for the study of the barriers to the electrification of MFMC includes quadruple helix partnerships [34]: academia researchers, private sector professionals, public policymakers, and users.

To begin with, academic researchers have identified the electrification of the transport sector as a solution to decarbonize this sector. Their studies mainly focused on optimization techniques to achieve this goal according to technical, environmental, and social targets based not only on current trends, but also on future ones too [7]. Private sector professionals are essential to materialize researchers’ results into suitable products for society regarding electric mobility. During recent years, most of them have started to change their internal combustion engine vehicles (ICEVs) business model to an EVs model, covering the whole production of this kind of vehicle together with other manufacturing elements such as chargers, electronic components … [35].

Public policymakers can promote policies to enhance transport sustainability in MFMC [16]. Their policies are normally based on academic findings and their own expertise, and they directly and indirectly influence users and private companies. These include municipal, regional and national planners that manage issues from daily traffic to strategic planning. Finally, users are the key stakeholders in the transition of transport towards sustainability since they benefit and have the right to mobility. Due to the recent introduction of EVs in MFMC, users are facing a large list of barriers, from technical to social ones [77]. Users group is the most heterogeneous one, resulting in possible biases. This situation matches the reality since each user could have personal interests, but they all have in common the use of EVs.

Considering these profiles and the selection process presented in section 2.2, 10 experts formed the final panel in the case study of Valencia. In order to prevent biasing outcomes, the number of experts in each profile was balanced: 3 experts were selected among academic researchers, 3 among users, 2 among public policymakers, and 2 among private sector professionals. All the experts knew the mobility status quo of Valencia and were used to driving in the city. Moreover, they have faced barriers to the electrification of urban transport in their studies, projects, policies, or even when travelling in EVs in Valencia. Finally, they all were willing to participate during the complex and long procedure. Therefore, they fulfilled the requirements to be selected as experts. Table 2 details the description of each expert. The research team played the role of ANP facilitators, aiding the experts throughout the whole process.

3.3. Selection of barriers and alternatives

Table 1 from section 2.1 presented a starting list of obstacles and transport alternatives based on an extensive literature review. This set compiled the general features of cities with an MFMC pattern [48,49]. However, the application of these criteria to each city requires an adjusting phase to cope with their individual requirements [25]. Thus, the research team, together with the panel of experts, developed a participatory process to adapt the initial list of obstacles and transport alternatives to the specific case study of Valencia. This stage indicated that some barriers were neglected in the initial list. For instance, the experts with the profile of users indicated the inconvenience that the lack of regulation of spaces for EVs recharging generates for them. i.e. chargers may be placed to the right or to the left of the car, at different distances, and with different plugs and, often, the place is occupied by a non-electric car. Thus, the importance of including this barrier (I2. Lack of regulation of spaces for EVs recharging) in the final list. Another example of additions for Valencia’s case are the barriers T4. Unreliable operation of recharging points and T2. Fast changes in EVs technology. The latter again based on the proposals of the experts from private companies and users, who stated that a number of potential EVs users would rather wait as long as diversity, prices and quality of the vehicles continue to increase almost annually.

Moreover, this participatory process also revealed that some initial barriers did not apply to Valencia. For example, CapEx and OpEx of recharging points’ structures arise as barriers to maintain EVs in communities where the penetration of EVs is high, like in Norway (52.17% of the market share in 2017), but not in places like Valencia where the market share of EVs in the whole country in 2017 was just 0.69% [7]. Similarly, the barrier “Negative impact on the electrical grid of non-scheduled recharge” was discarded for Valencia by the academic and the governmental groups of experts.

Finally, another conclusion of the participatory process was that some obstacles can be combined to avoid repetition. For instance, the final barrier I1. Insufficient subsidies for EVs development includes not only the financial support to enhance the introduction of EVs, but also the traffic taxes to discourage drivers from using ICEVs. Hence, it constitutes a combination of the two initial institutional barriers presented in Table 1. Regarding the clusters and the transport alternatives proposed in the initial list, both experts and the research team agreed on their suitability, so they were all included in the final set.

As a result of this phase, the initial list of 17 barriers and 5 transport alternatives was rearranged and reduced to 12 barriers divided in 5 clusters and 5 transport options, as Table 3 indicates.

3.4. ANP model

Once the experts agreed on the final set of barriers, clusters, and transport alternatives, their views about the different interrelationships among all these elements are reflected in the dependence matrix. To this issue, firstly the research team developed the barriers and alternatives dependence matrix, which showed the model elements in rows and columns. Then, experts filled this matrix according to the relationship between pairs of elements with data a_{mn}, which could be 0 or 1. If a_{mn} acquired the value of 1, then the element in row m influences the element in column n. On the other hand, if a_{mn} is 0, then there is no influence. Each expert, with the aid of the research team, was asked individually if variations of each element would influence the performance of another. Answers of all the experts were brought together and analyzed. The Pareto Principle was used to distinguish the small number of relationships that constitutes the biggest influence [25]. Hence, only those relationships with a clear agreement among experts regarding their influence were included in the final dependence matrix (Table 4).

These interrelationships finally determined the ANP model, presented in section 2.3 (Fig. 2). They were obtained with the aid of the software Super Decisions®. The model includes all the clusters with their corresponding barriers and transport alternatives, together with their interdependencies. Simple arrows indicate that an element from a cluster influences one or more elements from another cluster. Double arrows represent a bidirectional influence between elements from different clusters. Feedback arrows determine dependencies between elements of the same cluster.

Once the model was obtained, the experts conducted a pairwise comparison of the elements with the aid of a questionnaire, previously prepared by the research team (Table 5). Hence, the inclusion of their answers in the model allowed the obtention of ANP results for each expert. Moreover, the software Super Decisions® provided the inconsistency ratio of each group of judgements along with the unweighted dependence and limit supermatrices derived from the model.

The questionnaire was filled in by means of an interview, and processed by means of Super Decisions®. During the interviews, all doubts were cleared up, and all the experts' insights and comments were discussed and saved for later interpretation of the outcomes. Besides, the eventual inconsistencies calculated by the software, were presented to the interviewees, and sorted out with them. Finally, once the ANP was applied and the outcomes obtained, experts were shown the figures and asked for confirmation. In all cases they agreed that the results showed what they knew, or their intuition told them, about the barriers to EVs in Valencia.

4. Results and discussion

The first result of the research is the list of the influential criteria that affect the development of the urban transport electrification process in MFMC (Table 1). This list applies to any kind of these cities with a similar geographical situation, government and orography, as well as the methodology, which fits any case study in both the specific MCDM method and the four-helix stakeholder selection.

Table 2
Panel of experts for the case study.

Category	Stakeholder	
	Identification	Description
Academia researchers	Ac-1	Director of the Electrical Engineering Department in a public university of Valencia, who manages the University Master of Electric Mobility and whose research is specialized in recharge of EVs.
	Ac-2	Researcher from a Valencian investigation center, who is specialized in sustainable transport based on EVs introduction to the sector.
	Ac-3	Co-head of the Renewable Energy and Sustainable Transport Area of an important energy research institute in Valencia, focused on electric mobility.
Private sector professionals	Priv-1	Head of a cooperative company for shared electric mobility in Comunidad Valenciana.
	Priv-2	Engineer in an international company founded in Valencia specialized in electronic components' production for EVs and EVs chargers.
Public policymakers	Pub-1	Researcher specialized in public transport policies for the city of Valencia.
	Pub-2	Assistant director of the public transport system of Valencia.
Users	Us-1	Frequent user of shared EVs in the city and coordinator of a chair for urban energy transition in Valencia.
	Us-2	Regular driver of shared EVs in the city and head of an energy research institute in Valencia.
	Us-3	Owner of a hybrid electric vehicle and usual driver of shared EVs in Valencia. He is also a researcher with experience in electricity markets.

In contrast, the specificities of the application would arise in the fieldwork and experts' assessments of each particular case. Therefore, the different stakeholder experts may rethink the list of the final barriers for the ANP in the specific case study (Table 3) and discard those factors that may not be that influential. The considered alternatives are also common for MFMC, but its description and particularities may differ from one city to another. Experts can vary and some of the groups may acquire larger importance considering a specific stakeholder's analysis of the project. Finally, the relationships between elements (Table 4) of the network and the influences, affections, and weighted importance arising from the expert knowledge will also probably be different from case to case.

4.1. Influential barriers

Following the barrier and alternative selection to set up the ANP network, the different experts answered a questionnaire about mutual influences (Table 5) that were then introduced to Super Decisions software®. Each questionnaire ended in different result matrixes that expressed the judgments of each expert regarding the relationships among elements and clusters. The ANP procedure gave back the Limit matrix that represented the total weight of each barrier and alternative, as proposed by Saaty [24]. To easily compare them, the results were a normalization between barriers and a normalization between alternatives, so all the obstacles added one for one expert and all the alternatives added one too.

Fig. 3 to Fig. 5 present the aggregated and one by one results of the importance and values of barriers in the model (aggregation made by group as there were different number of experts per group). These figures place the factors as axis values and are grouped by clusters. The levels represent the relative importance of each criterion given by the experts (aggregated or individually). These figures group experts by their role and, although their judgments tend to be similar, they also present some significant differences. Experts' differing opinions show not all stakeholders perceive barriers as affecting similarly the different alternatives.

Fig. 3 (a) and (b) present the aggregated results of the ANP calculations of all groups, and experts grouped by role. To do so, the aggregation method is the Geometric Mean of judgments as prescribed by Saaty [24]. These figures show how differences among experts compensate and the average numbers are more moderate, allowing us to see what the most influential barriers on average are. Besides, the profiles of the four groups have a similar position regarding the barriers, although there are differences among the individuals (see Figs. 4 and 5).

Hence, the aggregated perception (Fig. 3 (a)) considers I1. Insufficient subsidies for EV development, T1. Battery autonomy power, and Ec1. CapEx of Batteries, the barriers affecting the electrification of urban transport in Valencia most. Barriers such as Ec2. CapEx of EVs, S2. Lack of knowledge about EVs, and En1. Life cycle of the EV batteries are also important barriers. Agents set as the most important barrier of the Institutional cluster, another one from the Technical cluster, and an Economic barrier. In this sense, two of these barriers relate to the cost or institutional benefits associated with having EVs, while the technical barrier relates to the performance of the vehicle itself.

The economic barriers are the ones that affect the transition from fossil transport to electrified alternatives most, the battery cost being more critical. Batteries have a cost decreasing path, but still represent the most expensive element of EVs. Associated with the economic barrier, I1. Insufficient subsidies for EVs development represent the most affecting barrier, which is correlated with a long tradition of subsidies to fossil vehicles in Spain [96]. The car manufacturing sector represents 8.5% of the national GDP and the existing plants only started

Table 3
Final list of barriers and electric mobility alternatives for the case study.

Clusters	Barriers	Description
Technical	T1. Battery autonomy power	The driving time of EVs without recharging depends on the autonomy power of their batteries, which can be insufficient for long travel distances.
	T2. Fast changes in EVs technology	EVs are experimenting fast and very notorious technological changes that have been taking place in short periods during recent years. This situation may delay the acquisition of EVs.
	T3. Long time recharging periods	The time needed to recharge EVs depends on the recharging strategy used (slow, medium, fast or ultra-fast). Unlike power engine vehicles, this process is not immediate. Using the ultra-fast recharge, it might still take 20 min approximately to recharge.
	T4. Unreliable operation of recharging points	It is not rare that some EVs recharging points remain unavailable to develop their function. Still, they appear as available in the electric recharging maps. This situation generates uncertainty and mistrust among drivers when planning to recharge their EVs.
Economic	Ec 1. CapEx of batteries	The capital expenditure on EVs batteries, which emerge as one of the main components of these vehicles, is still too high for their ordinary manufacturing.
	Ec2. CapEx of EVs	The capital expenditure on EVs is nowadays high compared to the average income of citizens. The limited offer of EVs models, together with the high cost of some EVs components and the novelty of the technology justify it.
Social	S1. Fear of changing pre-established driving patterns	Driving internal combustion engines has been a key identifying factor in Western culture. Sociologically, these patterns tend to lock in and make habit transition difficult.
	S2. Lack of knowledge of electric mobility	The lack of information is a market failure, and knowledge regarding EVs and their potential benefits is uncommon among consumers, who do not have a clear idea about EVs costs and fuel costs savings, infrastructure, and incentives of EVs.
Environmental	En1. Life cycle of EVs batteries	The whole environmental assessment of EVs batteries (lithium-ion), from the extraction of the raw materials to the final production, reveals a high CO2 footprint of these elements.
	En2. Finite batteries resources	Most EVs batteries are lithium-ion ones, whose main components (lithium and cobalt) are present in nature as finite resources.
Institutional	I1. Insufficient subsidies for EVs development	Spain and other MFMC have a large car industry based on Internal Combustion Engines. This has led to subsidies to purchase this kind of car and leaving the promotion of EVs at a lower scale compared with other European countries.
	I2. Lack of regulation of spaces for EVs recharging	Nowadays, there is no legislation to regulate parking in public spaces reserved for EVs recharging. Thus, EVs users confront a wide range of issues when they want to recharge their vehicles in such spaces. For instance, these spaces are sometimes occupied by ICEVS or the location of the recharging point obliges them to drive a long way.
Alternatives	A1. Mobility of services	Vehicles used by public services such as ambulance drivers, firefighters, and police to transport necessary material, goods, or people. These vehicles normally run on short distances and un-plannable routes. Their recharge takes place in their base platform (hospitals, firefighter stations, police stations …) and they should always be ready since the services provided become critical.
	A2. Freight transport	Transport used to move and deliver goods, commodities, and cargo inside urban areas. These vehicles normally run on long distances and plannable routes. Their recharge takes place in their base platform, although some of them can promptly also recharge at public stations.
	A3. Private passenger transport	Transport alternative that enables the individual transportation of passengers that own a vehicle. These vehicles present a wide variability dynamic since they depend on users' necessities. They can run on long or short distances and plannable or un-plannable routes. Their recharge takes place both at private parking and public stations or recharging points.
	A4. Private transport sharing	Transport that individual travelers share either as a group or is facilitated by public organizations, private companies, or by their own interests. These vehicles run on short distances and un-plannable routes. Users do not need to worry about their recharge. When transport sharing depends on organizations, companies etc., recharge normally takes place in their base platform. However, when it depends on individual travelers, they normally recharge at private parking.
	A5. Public passenger transport	Transport alternative that allows the collective transportation of passengers that have paid a tariff. These vehicles run on long distances and completely planned routes. Their recharge always takes place in their base platform.

manufacturing EVs in the past year [97].

We find it important to highlight that even though experts did not initially give importance to the Environmental barriers, both ended up being influential to the adoption of EVs after the questionnaire. Considering, En1. Life cycle of the EVs batteries, this can also relate to the increasing attention paid by public administrations regarding waste management and material reusing and recycling. In the case of En2. Finite batteries resources, this arises from the general scarcity of materials that occurred during the COVID-19 pandemic, and the periodical warnings about the scarcity of Lithium and other rare metals involved in the manufacturing of EVs.

In contrast, the lack of importance given to T3. Long time recharging periods and T4. Unreliable operation of recharging points, contradicts what other authors find [52,53]. This result is related to the fact that the survey focused on mobility within the city, and asked for the barriers to the current deployment of EVs in the short term. Hence, experts allocated more importance to the barriers related to the vehicles than the

Table 4
Dependence matrix for the case study.

	T1	T2	T3	T4	Ec1	Ec2	S1	S2	En1	En2	I1	I2	A1	A2	A3	A4	A5
T1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
T2	1	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	1
T3	1	1	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1
T4	1	1	1	0	0	0	1	0	0	0	1	1	1	1	1	1	1
Ec1	1	1	0	0	0	1	0	0	1	1	1	0	1	1	1	1	1
Ec2	0	1	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1
S1	1	0	1	0	0	0	0	1	0	0	1	1	1	1	1	1	1
S2	1	0	1	1	0	0	1	0	0	0	1	0	1	1	1	1	1
En1	1	0	1	0	1	1	0	0	0	1	0	0	1	1	1	1	1
En2	1	1	1	0	1	1	0	0	1	0	0	0	1	1	1	1	1
I1	0	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1
I2	1	0	1	0	0	0	1	1	0	0	0	0	1	1	1	1	1
A1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
A2	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
A3	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
A4	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
A5	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0

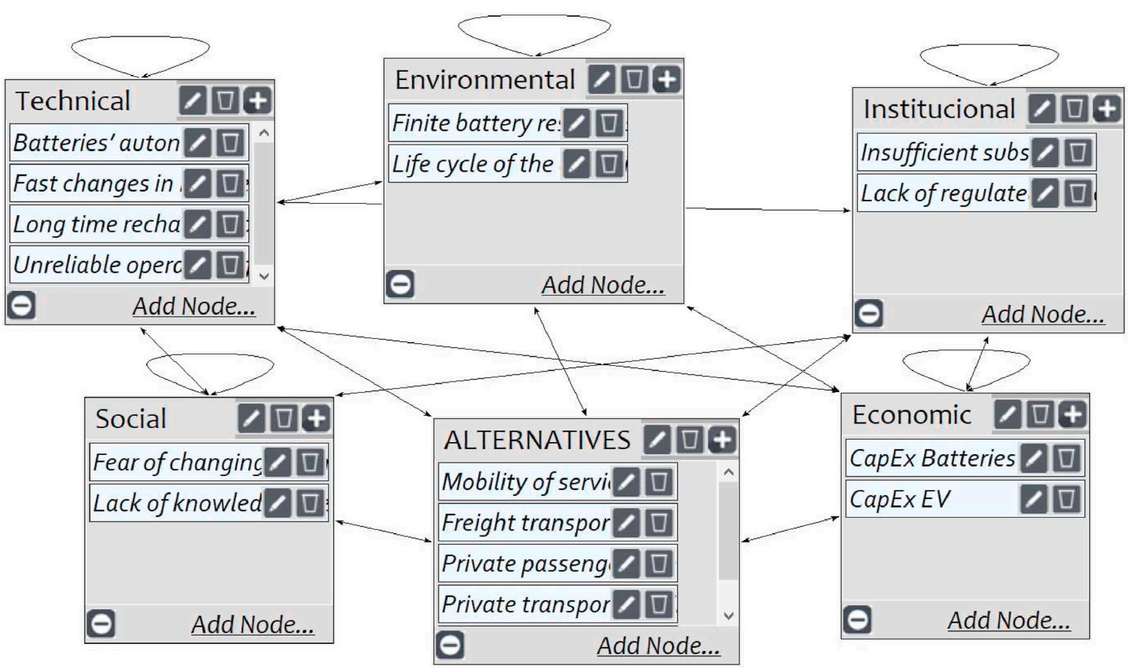

Fig. 2. ANP model for the case study. Software: Super Decisions ®

Table 5
Example of questions from the questionnaire.

1. Considering FAST CHANGES IN EVs TECHNOLOGY, which criterion has a greater influence on it: UNRELIABLE OPERATION OF RECHARGING POINTS or BATTERY AUTONOMY POWER?

	EX	VS	S	MO	=	MO	S	VS	EX	
Unreliable operation of recharging points	*9*	*7*	*5*	*3*	*1*	*3*	*5*	*7*	*9*	*Battery autonomy power*

2. Considering FAST CHANGES IN EVs TECHNOLOGY, which criterion has a greater influence on it: BATTERY AUTONOMY POWER or LONG TIME RECHARGING PERIODS?

	EX	VS	S	MO	=	MO	S	VS	EX	
Battery autonomy power	*9*	*7*	*5*	*3*	*1*	*3*	*5*	*7*	*9*	*Long time recharging periods*

EX: Extreme, VS: Very Strong, S: Strong, MO: Moderate, =: Equal barriers related to the infrastructure, contrary to what was found in the literature, see for example [11,17,51]. Besides, in the current situation, most of the early adopters of EVs would have recharging points at their private parking slots. Thus, experts always considered T1. Battery autonomy power as more important than the other three technical barriers, and the focus is on the vehicle's performance and costs, more than on other types of barriers.

Fig. 3 (b) shows the aggregated evaluation of the barriers by the expert group. The importance of the barriers has a similar distribution for all four groups. The group of users show a larger concern for the economic barriers, but they also state that T1. Battery autonomy power and S2. Lack of knowledge about EVs are more important for them than for other experts, i.e. they fear more problems or changes in their habits. Another divergence relates to the weight given to the environmental barriers. The public policymakers give more importance to En1. Life cycle of the EVs batteries, due to its responsibility in waste management,

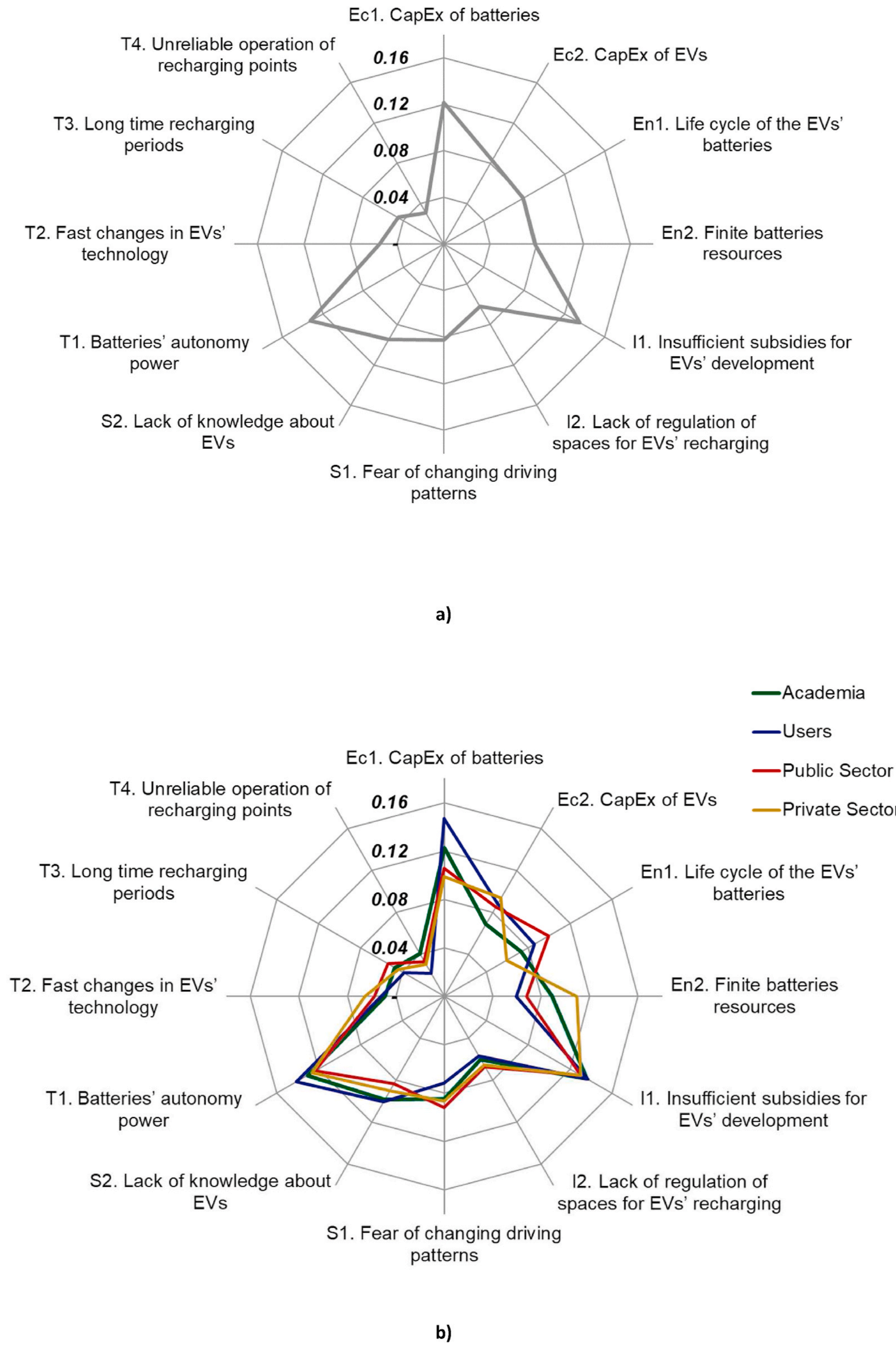

Fig. 3. Relative importance of the barriers. All stakeholders aggregated **(a)** and aggregated by group **(b)**.

and the private sector to En2. Finite batteries resources, as they see a problem in the future management of the raw materials.

Regarding the specific opinions of experts, Figs. 4 and 5 show the individual opinions of each expert organized by cluster. All three academic experts (Fig. 4 (a)) present similar opinions with small variations regarding barriers. This may be related to a similar profile of the three experts, with an engineering background. Users (Fig. 4 (b)) also show a similar distribution of weights and relative importance with minor differences in the weight attributed to the economic and environmental barriers. Again, users point out the importance given to the lack of subsidies and the high upfront costs of batteries.

Fig. 5 (a) and (b) present the same analysis but for the public policymakers and the private sector. Again, the results are homogeneous with small differences. In the case of Pub-2, which represents the

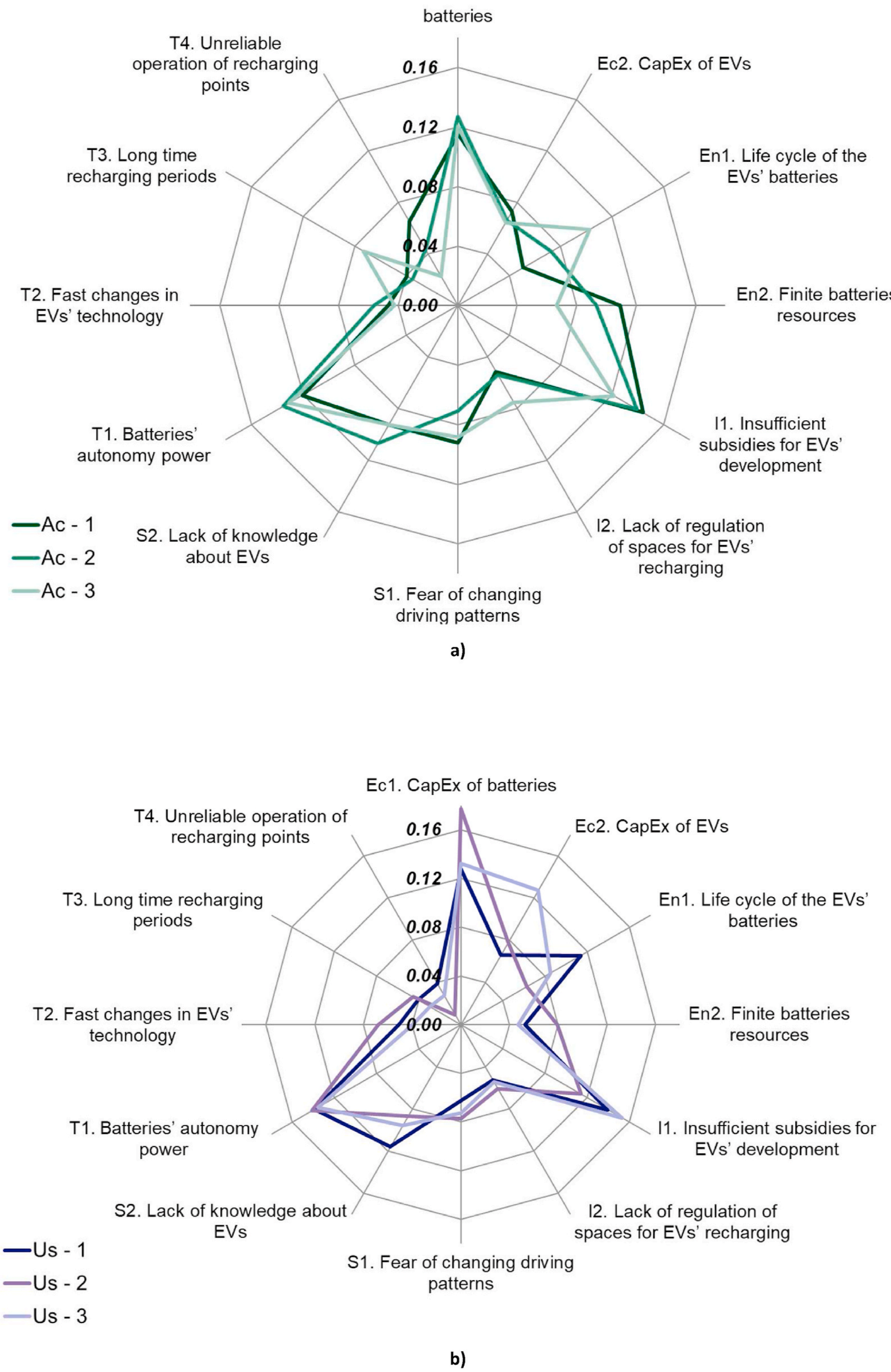

Fig. 4. Relative importance of the barriers. All academics **(a)** and all users **(b)**.

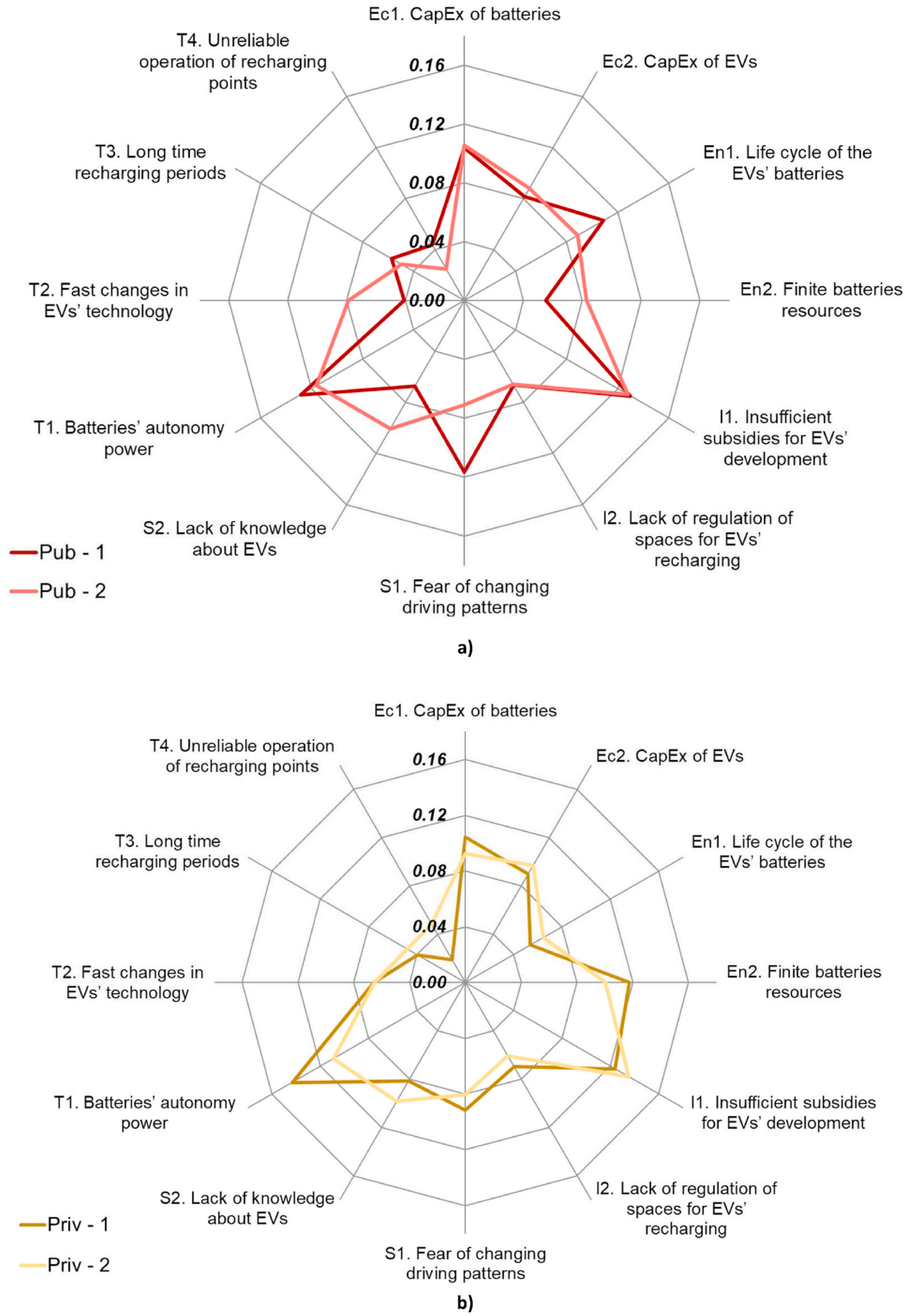

Fig. 5. Relative importance of the barriers. All public policy makers **(a)** and all private companies **(b)**.

assistant director of the public transport system of Valencia, T2. Fast changes in EVs technology, has a larger importance than for other experts due to the specific situation of the constant renovation of the company's fleet. In the case of the Private sector, barriers align in weights and show a similar opinion to all barriers.

4.2. Rank order of the urban transport alternatives by impact of the barriers

Fig. 6 shows the impact of the barriers on the five transport alternatives as determined by the group of experts and all duly aggregated. In aggregated terms, the alternative most affected by the barriers is A3. Private passenger transport, followed by A2. Freight transport, A4. Private transport sharing, A5. Public passenger transport, and A1. Mobility of Services. Experts consider the largest number of EVs will be private vehicles, and identify the difficulty to manage and direct individual private investment to the electrification of private vehicles. In contrast, the few vehicles included in A1. Mobility of Services and their particularities seem to the experts not to be affected.

The analysis of the barriers resulted in similar profiles among experts, as Figs. 4 and 5 showed. Nevertheless, how these barriers affect the alternatives largely differ among them based on how much experts believe the alternative relates to the barrier, as Fig. 6 indicates. The public policymakers state that A5. Public passenger transport is the most affected alternative. In contrast, users believe that A3. Private passenger transport is the most affected one. Therefore, academia and the private sector show less divergences on barrier effect on the alternatives than the other two groups, A3. Private passenger transport and A2. Freight transport being the most affected ones. The aggregation shows that all the alternatives encounter barriers to their development and find that all the alternatives should be supported to deploy their complementary potential benefits.

When analyzing the opinion of each expert for each alternative, larger differences exist compared with the group analysis, as Fig. 7 shows. Large differences also exist between experts within each group. Academia shows the most homogeneous opinions, giving importance to A2. Freight Transport. Users also gave similar importance to all alternatives except for A3. Private passenger transport and A5. Public passenger transport. In particular, large differences appear between User 1 and User 3, with User 3 giving more importance to public transport and less to private. Regarding the public policymakers' opinions, the researcher specializing in public transport policies for the city (Pub-1) gives more importance to public transport.

Finally, the private sector also presents a large divergence between the two experts. On the one hand, the expert working in a transport sharing company (Priv-1) expresses wider barrier effects to A4. Private transport sharing and A2. Freight transport. On the other hand, the expert working in a company that builds EVs electronic components and chargers mentions A3. Private passenger transport and A5. Public passenger transport as the most affected alternatives. This shows a wider concern with each expert's own market niches.

To sum up, the experts show a similar evaluation for the barriers. However, when assessing how the barriers affect the alternatives, each expert perceives that the alternative closest to its activity is the most affected. This is a surprising finding as previously they seemed to be alternatives clearly more hindered (A3. Private passenger transport, A2. Freight transport) than others (A4. Private transport sharing, A5. Public passenger transport) [35].

4.3. *Partial analysis. Influence of the barriers on the alternatives*

ANP permits partial studies for a deeper understanding of the mutual relationships. For instance, how the barriers influence each other and the alternatives. Fig. 8 presents the weighted supermatrix of the procedure formed by the aggregation of all the experts' judgements. The partial analysis helps to understand the general results better. The most influential barriers to alternatives are Ec1. CapEx of Batteries, I1. Insufficient subsidies for EVs development, and S2. Lack of knowledge about EVs (Fig. 8). However, T1. Battery autonomy power, is not as influential as in the previous Fig. 3. The influence of one barrier on one alternative is a combination of how influential the barrier is, and how much it influences the alternative, this combined with the weight of the cluster, (see Fig. 9). As the Technical cluster, aggregated, is less influential than the Social cluster, the barriers of the second overcome the barriers of the first.

5. Conclusions

There is an urgent need to decarbonize our economies, where cities represent about 50% of total GHG emissions. From this share, transport represents around a quarter of cities' emissions. Thus, urban areas will have to decarbonize their transport systems to ensure climate action. This process is largely related to the rationalization of mobility, the electrification of the system: from private cars to public transport and other usages, together with a cleaner electricity mix.

Here, we present a methodology to assess the barriers to the introduction of EVs in urban transport areas. This method combines context analysis, literature review, and the application of ANP, with the support of a panel of experts. This methodology has focused on modeling a

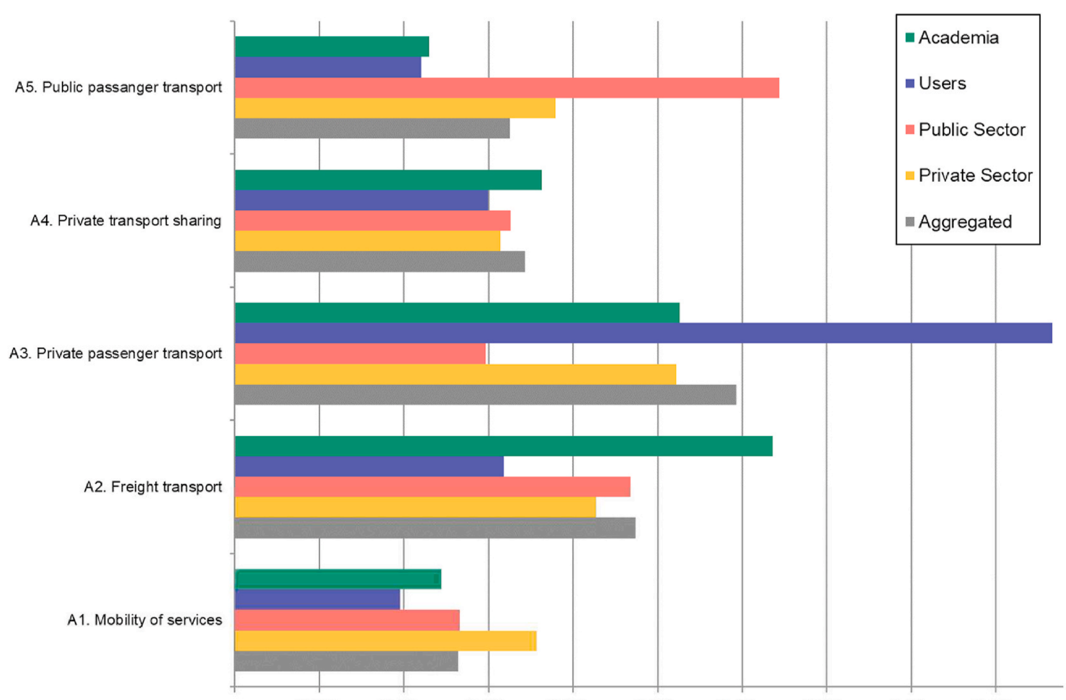

Fig. 6. Aggregated relative importance of the transport alternatives.

specific city pattern: Mediterranean flat medium city pattern. Such modeling includes all the compact cities with Mediterranean climatology, architecture, flat orography, medium size and a mature electricity distribution system.

To prove the feasibility of the multicriteria method, the authors applied it to Valencia (Spain) in a case study. Hence, we analyzed the main barriers affecting the electrification of urban transport in the city using ANP. We based the analysis on the knowledge of a group of ten experts, who represented the different agents in an innovation system: academia, private sector, public policy, and society. The expert panel was designed to be as comprehensive and balanced as possible, following the three selection rules: broad expertise, belonging to a particular stakeholder group, and willingness to participate in the demanding research. Unfortunately, it was not possible to ensure that all four groups had the same number of participants, yet all groups were diverse and covered the spectrum of opinions and interest groups. To avoid bias in the added results, the results are aggregated by groups and not by individuals, and the individual results are shown throughout.

The main findings and contribution of this work are the following. First, a proposal of a methodology to use ANP with a panel of experts from the quadruple helix of system innovation. The participatory procedure allows us to understand and analyze the barriers that MFMC face in their efforts to electrify their urban transport systems. Second, and a contribution in itself, a list of influential barriers to the electrification of the different urban transport alternatives in MFMC was considered. Considering the specific case study (Valencia) and basing the debate on this initial list, the selected experts agreed on a final list of 12 barriers grouped in 5 clusters: economic, environmental, institutional, social, and technical. Our study incorporates the novelty of analyzing and grouping a wide variety of criteria as a whole (and non-partial studies like previous research work), with a multicriteria and quadruple helix perspective. Furthermore, expert knowledge based on the case study nourished our research with 3 completely new obstacles, which had not been previously contemplated in the scientific literature: T2. Fast changes in EVs technology, T4. Unreliable operation of recharging points, I2. Lack of regulation of spaces for EVs recharging. Third, a prioritization of barriers regarding their influence was obtained, together with the rank order of transport alternatives regarding how affected they are, both aggregated and sorted by the group of experts.

Specifically, the research found that all the expert groups had a similar opinion on which were the most affecting barriers regarding the introduction of urban EVs in Valencia: I1. Insufficient subsidies for EVs development, T1. Battery autonomy power, and Ec1. CapEx of Batteries. The lack of subsidies must be understood as an imbalance, that is to say, fossil fuel based vehicles are still more subsidized overall than EVs in Spain, and hence Valencia. This way, private owners to be, in particular, are discouraged from opting for EVs. Furthermore, the assessment focus on intra-mobility and not inter-city mobility; this together with a focus on the short term, i.e., asking about the barriers to current EVs adoption, found social, environmental and infrastructure barriers less important than vehicles. Another finding is environmental barriers, not normally present in literature, were found to be relevant although not outstanding.

In contrast with barriers, when asked about alternatives, each group of experts tended to be more influenced by barriers affecting the alternative that related more to their interests, daily work, or research. In this sense, experts of the public sector expressed that A5. Public passenger transport was the most affected alternative while users said that A3. Private passenger transport was the most affected one. Furthermore, all the experts believe A3. Private passenger transport is important due to its volume, and because those users have less margin of action. A1. Mobility of Services is considered less hindered, and would need less support, as the vehicles can be charged in the garage, and they are mainly owned by the public administration. Half of the experts believe the same of A5. Public passenger transport; while the other half, and particularly, the managers of public transport, declare this sort of transport needs to be moving during long services and, thus, it is clearly affected by barriers opposed to this performance: CapEx of Batteries, Autonomy of Batteries, etc. A2. Freight transport is characterized by carrying heavy payloads, and having to frequently start and stop the engine, which shortens the lifespan of batteries. In this sense, A5. Public passenger transport and A2. Freight transport may wait longer before going electric, until batteries are less expensive and perform better. In these two cases, S1. Fear of changing driving patterns also plays a role.

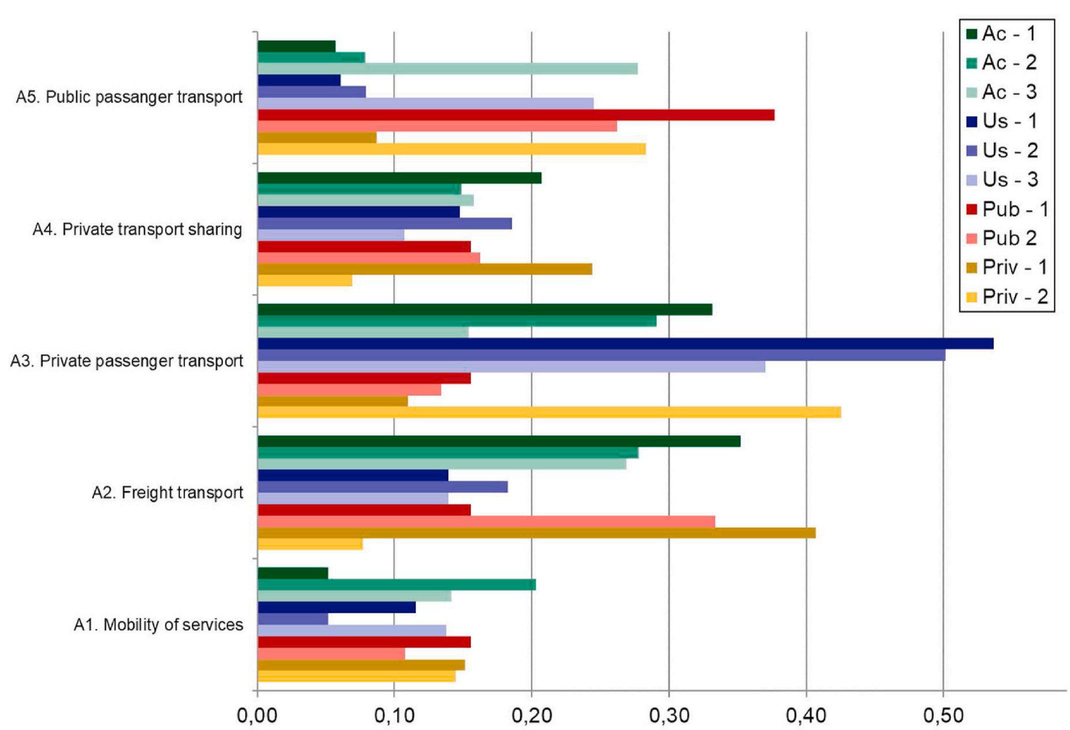

Fig. 7. Relative importance of the transport alternatives.

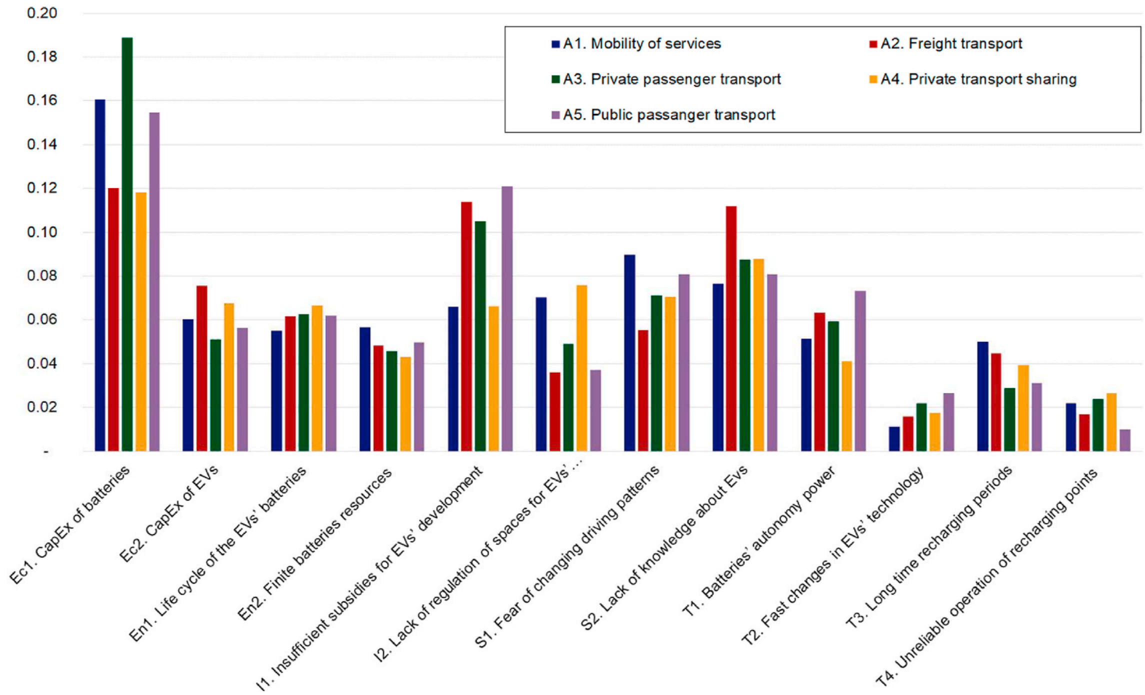

Fig. 8. Relative importance of barriers by transport alternatives.

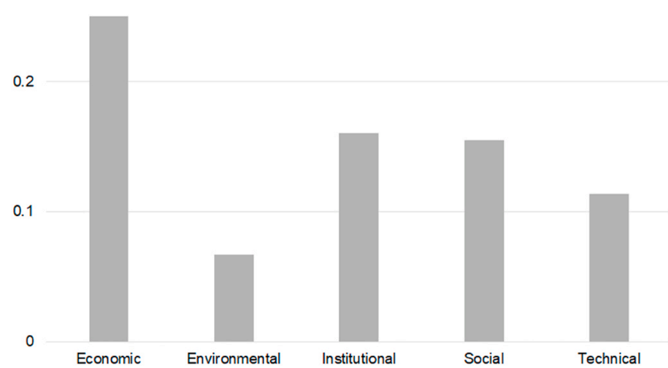

Fig. 9. Aggregated weight of the clusters.

A4. Private transport sharing has more in common with A3. Private passenger transport, although, battery replacement is supposed to be more frequent in the shared vehicle. The lack of recharging points is not deemed so important as they are expected to be parked connected to chargers (as the few units in Valencia currently are). While this result is a finding of the study itself, such a bias in experts' preferences can be a problem for policy making recommendations. From that point of view, the bias can be addressed by considering each technology separately and analyzing the barriers that most influence them, without considering comparisons between technologies.

The results extracted from this work shed light on this multi-faceted and uncertain situation. Besides, they can assist policymakers with overcoming barriers to the electrification of the Valencian urban transport sector. Economic incentives have been found to be key to EVs deployment, incidentally, aligning with the key economic drivers, of EVs deployment in Northern Europe. In particular, one avenue for future research has been identified: expanding research on how specific barriers influence specific modes of mobility. Cause-effect relationships must be identified to address the removal or mitigation of those barriers, or their impact on each mode of mobility.

Credit author statement

Paula Bastida-Molina: Conceptualization, Methodology, Investigation Writing Original Draft, Writing-Review&Editing, Supervision. **David Ribó-Pérez**: Methodology, Software, Visualization, Writing Original Draft. **Tomás Gómez-Navarro**: Methodology, Software, Validation, Writing Original Draft, Writing-Review&Editing. **Elías Hurtado-Pérez**: Validation, Resources, Writing-Review&Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2022.112649.

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