Identifying and Prioritizing Sustainable Urban Mobility Barriers through a Modified Delphi-AHP Approach

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Abstract: Sustainable urban mobility has been the epicenter both at the scientific and administrative level during the last decades, with a high number of relevant research projects, awareness campaigns, and other initiatives taking place at the local, national, and international level. However, many urban areas have so far achieved limited results in this direction because of political, institutional, organizational, technological, infrastructural, and socio-economic barriers as well as unforeseeable (e.g., COVID-19) conditions. The overall aim of the present research study is to support policymaking by proposing a methodology that identifies and prioritizes the sustainable mobility barriers for a specific urban area, with a view to developing effective policies. Towards this purpose, this work provides, in the first phase, a comprehensive inventory of barriers based on a literature review. In the second phase, a methodology using as a basic scientific tool a modified Delphi-AHP is proposed for the adaptation of this inventory to a specific urban area and for both the evaluation and prioritization of sustainable mobility barriers. The whole process is then applied in Thessaloniki, Greece, a European city suffering from many problems related to sustainable mobility. The above pilot application confirms that this approach can be integrated as a supporting tool in the first steps of sustainable urban mobility plans (SUMPs).

Keywords: sustainable urban mobility; barriers prioritization; transport policy; Delphi; AHP

1. Introduction

Nowadays urban areas constitute 55% of the world’s population, with an increase to almost 70% expected by 2050 [1]. The share of urban inhabitants is very high in some continents such as in the Americas (over 80%) and Europe (74%), while urbanization increases at high rates in others such as Asia [2]. Cities today occupy only 3% of the available land but produce 80% of the global GDP and 95% of carbon emissions through the transport and energy sectors [1,2]. Urban transport, in particular, is held responsible for 7 million premature deaths and over 600,000 road traffic fatalities annually [1,3].

The above evidence suggests that the urban transport system plays an important role to address the increasing mobility needs of cities. However, it also generates a wide array of negative impacts on society and the environment. The challenge of effectively coping with the growing mobility demand, at the least possible economic, social, and environmental cost for today and the future, comprises the main goal of sustainable transport policy over the last three decades [4]. Towards this goal, various models, systems, methodologies, techniques, guidelines, and awareness campaigns are being developed worldwide [5,6].

During this period, cities have undoubtedly achieved many positive results in promoting the economic, social, and environmental pillars of sustainable mobility. Their efforts have been focusing mainly on the aspects of competitiveness and effectiveness of their transport services; the affordability, inclusiveness, accessibility, safety, and security of their mobility networks; and the energy intensity, noise, visual intrusion, pollutant emissions,
and greenhouse gases produced by their transport systems. However, the performance in the above-mentioned aspects varies significantly between different cities [7]. Researchers argue that the integration of the principles and methods of sustainable mobility to the transport planning framework of different cities remains a challenging process. This is due to the dynamic, case-specific conditions which derive from the mix of general and local interests, trends, and overarching policies [8–10].

In Europe, the guidelines to integrate the sustainable mobility principles to contemporary transport planning, i.e., the Sustainable Urban Mobility Plan (SUMP) guidelines, were developed in 2013 and recently revised [11]. In spite of the strong uptake of the SUMP guidelines by local authorities and planners over this period, many mobility problems are still observed in European cities [12]. Nowadays, the shift to the “sustainable mobility paradigm” [13] is more crucial and timelier than ever. It is crucial due to the urgent need of cities to provide “safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons” [14]. Moreover, the recent European Commission’s Sustainable and Smart Mobility Strategy [15] emphasizes the role of urban mobility systems for seamless first-mile and last-mile travelling along the Trans-European Transport Network (TEN-T). The strategy also aims to promote sustainable and healthy urban mobility solutions in order to (a) achieve the goal of reducing greenhouse gases by at least 55% by 2030 and achieve climate neutrality by 2050, and to (b) improve the resilience of the transport system against crises, such as the COVID-19 pandemic.

In addition, the shift towards sustainable mobility is timely due to the emergence of the so-called “digital era” and the fourth industrial revolution (Industry 4.0). The World Economic Forum [16] identifies three technological megatrends of this new era, i.e., connectivity, artificial intelligence, and flexible automation. The combination of technological achievements concerning these megatrends are leading to the development of enhanced or disruptive technologies for the transport system, such as autonomous road vehicles, drones, and micro-mobility modes, which are expected to change user preferences [17–19]. Furthermore, “greener” engine and fuel technologies, mainly in the context of electromobility (e-mobility), are becoming available for the service of daily urban transport demand. Another main trend concerns the emergence of innovative mobility concepts, such as Mobility as a Service (MaaS) [20]. Enhanced connectivity allows for increased interaction between the transport, telecommunication, and energy networks in the context of “smart” cities [21]. Information technologies allow for dynamic mobility services. As a consequence, big data is being produced with the potential to support planning purposes under the appropriate data governance framework [22].

In this challenging context, a basic step towards the successful integration of the sustainable mobility principles in the transport planning framework of a specific urban area comprises the identification, understanding, and prioritization of different types of barriers that have to be overcome. It is worth mentioning that the SUMP guidelines (Step 3: “Analyze Mobility Situation”) highlight the need for analyzing the mobility situation in terms of problems and opportunities for all modes in the entire functional urban area. The guidelines also emphasize the importance of adapting to the local needs and specific features of the examined city [11].

Towards this purpose, this work develops and proposes a methodology that identifies and prioritizes the sustainable urban mobility barriers for a specific urban area. This step is of high importance towards developing and implementing effective sustainable mobility policies in an urban area, as the comprehensive understanding of the problem and of all related parameters constitute a fundamental precondition for finding the most effective solutions. Thus, it is necessary to identify and prioritize the most important sustainable urban mobility barriers through an “individualized” approach, which adapts the barriers identified by the international planning community to the local context as well as to the specific needs and expectations of an urban area. This allows for the development of the
appropriate basis on which the planners and policy makers can formulate and implement effective policies to promote sustainable mobility by directly “targeting” the main barriers.

The present research contributes to the existing literature in two ways. Firstly, in an initial phase, a comprehensive inventory of sustainable mobility barriers based on a thorough review of international literature is formed. This inventory can be used as a “pool” from which policy-makers, transport planners, and decision-analysts can extract sustainable mobility barriers for any urban area under study. Secondly, in the next phase of the research study, a modified Delphi-AHP (analytical hierarchy process) approach is proposed as a methodology to identify and prioritize sustainable mobility barriers for a specific urban area after adapting the aforementioned barrier inventory to the special characteristics and needs of the examined area. The identification and prioritization are conducted by experts with extensive local knowledge. In this way, the most important barriers towards sustainable urban mobility are identified and prioritized, providing the necessary knowledge for their effective overcoming through the development and implementation of appropriate policies.

In order to test the applicability of the proposed methodology, the whole process is applied for the city of Thessaloniki, Greece. The specific city was selected as a case-study area as it is one of the pioneers in Greece in the conduction of sustainable urban mobility plans. However, it suffers from many persisting mobility problems, affecting both mechanized and active transport. Moreover, the implementation of different sustainable mobility policies in the city often leads to ambiguous results. The study area is also characterized by a unique geography as well as a long historical and cultural heritage that affect the urban development. Taking these conditions into account, the methodology was successfully tested, leading to the identification and prioritization of administrative issues, infrastructure gaps, and behavioral aspects as the main barriers to the promotion of sustainable mobility in Thessaloniki, a city suffering greatly from the violation of sustainable mobility principles; the relevant results are presented. It should be mentioned that the problems related to sustainable urban mobility are also found in many other Greek cities, despite initiatives such as the Sustainable Urban Mobility Plan.

2. Materials and Methods

2.1. Phase 1: Inventory of Sustainable Urban Mobility Barriers Deriving from the Literature Review

The scope of the first phase of the present research study is the investigation and categorization of the various barriers related to the development and implementation of effective sustainable urban mobility policies. The identification and classification of such barriers has been addressed by scholars [23–29]. Four main categories are identified by [23] and [24], i.e., legal and institutional, financial, political and cultural, and practical and technological. In a similar work, six categories are identified by [25], i.e., resource-related, institutional and political, social and cultural, legal, side effects, and other physical barriers. In [26], seven categories of barriers are identified, i.e., cultural, political, legal, organizational, knowledge-related, technological, and financial. Bardal et al. [27] also highlighted that: “the categories are partly overlapping and not mutually exclusive, and that one measure is likely to address several types of barriers”. Based on the case studies of the cities of Oslo (Norway) and Copenhagen (Denmark), Næss et al. [28] highlighted, as an important barrier, the lack of coordination between planners and decision-makers at different sectoral and territorial levels. Bezerra et al. [5] focused on the relevant barriers for small and medium-sized urban areas in Sao Paolo (Brazil). The pandemic of COVID-19 is also identified as a strong sustainable mobility barrier as it seems to favor the use of private car use over public transport or any sharing mobility solutions [29–31].

Based on the above literature review, the most common barriers towards sustainable urban mobility are shown in Table 1. Obviously, forming a common list of barriers towards sustainable mobility for all the urban areas facing sustainable mobility problems is not feasible. Thus, this list is expected to be different for each urban area, depending on its special characteristics and the special conditions in each period (e.g., COVID-19 effects).
Thus, the list shown in Table 1 (created on the basis of the relevant literature review) can serve as a basis to form a unique list for each urban area, with certain barriers having to be removed and probably others to be added by taking into account the special characteristics and needs of each urban area under study.

| Category | Barsers |
|----------|---------|
| Financial/economic (related to budget constraints) | • Budget constraints for the development of studies and sustainable urban mobility plans.  
• Budget constraints for the implementation of studies and sustainable urban mobility plans.  
• Insufficient incentives (subsidies, tax exemption, etc.) or inadequate purchasing power for the acquisition of new vehicle technologies (e.g., electric vehicles), both for citizens and for companies.  
• High ticket price for public transport use.  
• Inefficient policing against illegal parking due to insufficient number of municipal policemen. |
| Knowledge-based (related to data availability, employees’ expertise, etc.) | • Low expertise/experience of municipality/public employees concerning sustainable urban mobility issues or difficulty in finding adequately skilled associates/contractors.  
• Lack of data or data reliability for monitoring and assessing the performance of the current situation or of the measures under implementation.  
• Low maturity level of existing studies. |
| Organizational (related to bureaucracy and organization) | • High complexity of bureaucratic processes, leading to implementation delays.  
• Lack of efficient coordination and cooperation between local, regional, and national authorities in decision-making (at the same administrative level or across administrative levels).  
• Difficulty in compromising different stakeholders’ interests (transport authorities, contractors, pedestrians, bicyclists, drivers, shop-owners, etc.) through participatory processes, constructive dialogue, and consensus. |
| Social and cultural (related to mentality, education, and behavioral aspects) | • Mobility choices in favor of private car use (e.g., for security, comfort, speed, and prestige reasons) over public transport, car-pooling, car-sharing, bicycles, etc.  
• Inappropriate behavior of drivers of motorized vehicles towards other road users and the use of public transport (e.g., illegal parking on sidewalks, pedestrian areas, bus lanes, bicycles lanes, etc.)  
• Inadequate level of citizens’ education and awareness regarding the significance of sustainable urban mobility and sustainable transport modes.  
• Sense of insecurity due to high criminality levels in certain areas of the city, resulting in the discouragement of walking, cycling, micromobility, car-pooling, etc.  
• Indifference of citizens to participate in public consultation and participatory planning due to their perception that their participation will not have a substantial impact on decision-making.  
• Difficulty in citizens’ and other stakeholders’ engagement to public consultation and participatory processes (e.g., relevant fora, platforms, etc.). |
2.2. Phase 2: Adaptation to a Specific Urban Area and Evaluation and Prioritization of Sustainable Mobility Barriers

Phase 2 of the present research study is based on a modified Delphi-AHP methodology for the adaptation, to the specific features of a city, of the barriers derived from

| Category | Barriers |
|----------|----------|
| City particularities (related to topography, urban sprawl, climate and weather conditions, and other special city characteristics) | • City’s layout (in relation to geomorphological constraints, such as mountains, sea-front, etc.)<br>• City’s topography (e.g., elevation which may hinder moving on foot or by bicycle, or not allowing for tramway infrastructure)<br>• Climate conditions (e.g., extremely high or low temperature that might discourage walking or cycling)<br>• Underground features (groundwater, geological formations, etc.) which may hinder or even exclude certain transport infrastructure solutions (e.g., metropolitan railway).<br>• Monuments and archeological findings, either underground or on the surface, which may have specificities (e.g., historical value, vulnerability to vibration or pollution, etc.) that obstruct the implementation of transport infrastructure and mobility interventions. |
| Technological (related to technology exploitation at infrastructure and equipment level) | • Use of intelligent transport systems in favor of motorized transport over other road users due to the misperception of the “smart” city and “smart” mobility concepts<br>• Insufficient technological means (e.g., ITS) for the management and control of mobility, parking, information provision, etc.<br>• Lack of appropriately designed infrastructure for the promotion of environmentally friendly mobility solutions such as bicycle lanes, walkable areas, etc.<br>• Insufficient infrastructure for the recharging/refueling of environmentally friendly vehicles (e.g., electric vehicles).<br>• Ineffective design and management of public transport infrastructure and networks, as well as insufficient fleet (including environmentally friendly vehicles).<br>• Limited availability of alternative and complementary public transport modes.<br>• Insufficient infrastructure and services for intermodality (e.g., park and ride). |
| Unforeseeable/temporary barriers (barriers of a temporary/unforeseeable nature) | • Negative impacts on mobility conditions during the construction phase of transport infrastructure and physical interventions.<br>• Preference of private car use over public transport modes, car-pooling, car-sharing, etc., due to individual and public security as well as health concerns in the case of extraordinary circumstances (e.g., COVID-19 pandemic). |
| Legal and institutional (related to law, rules, administration, etc.) | • Inadequate legal and regulatory framework related to the compulsory provision of parking places in new buildings and urban developments.<br>• Inadequate legal framework for micromobility and the co-existence with other transport modes.<br>• Inefficient organization and management of logistics (first and last mile) and loading/unloading schemes to alleviate impact of traffic and parking conditions. |
| Political (related to politics) | • Decision-making not based on a scientific, knowledge-based methodology that integrates all parameters and stakeholder positions.<br>• Inadequate time for local authorities to implement sustainable urban mobility plans and relevant studies due to possible shift (elections) at regular periods. |
the inventory of Phase 1 and both their comparative evaluation and prioritization to support policy-making.

The analytic hierarchy process (AHP) is a multi-criteria analysis (MCA) method applied for the evaluation and prioritization of alternatives based on a set of criteria, which are weighted through the execution of pair-wise comparisons. AHP is the most applied MCA method in regard to transport projects [32] in its traditional or fuzzy form, or in combination with other MCA methods, such as VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), not only for the selection of the optimal solution but for the extraction of criteria weights as well. As indicative examples, the following can be mentioned: AHP is applied for the selection of the optimal dry port location of the Seaport Rijeka (Croatia) in [33]. AHP and VIKOR are combined in [34] for the prioritization and optimal selection of sustainable mobility enhancements in Valencia (Spain). Infrastructure alternatives for autonomous electric vehicles are evaluated and prioritized through a combined application of AHP-VIKOR and AHP-TOPSIS models in [35]. AHP is applied for the evaluation of public road transportation vehicles in Madrid (Spain) based on alternative engine technologies and combustion characteristics in [36]. A fuzzy AHP-TOPSIS approach is adopted for the selection of multimodal freight transportation routes in [37]. An interval type-2 fuzzy AHP in combination with TOPSIS is applied for the selection of the appropriate shiploader type in maritime transportation in [38].

In spite of being a multi-criteria analysis method mainly aimed at selecting one or more solutions for a decision problem, AHP, in combination with traditional Delphi in certain cases, has been applied for the prioritization of barriers regarding various sectors, as in the following cases: Barriers to energy efficiency in small industry clusters are identified and prioritized in [39]. Barriers to the implementation of cleaner production in small and medium-sized enterprises in China are identified and prioritized by [40]. Coordination barriers in humanitarian supply chain management are identified and prioritized in [41]. Identification and prioritization of barriers to total quality management implementation in the service industry is realized by [42]. Waste management barriers in developing country hospitals are identified and prioritized in [43]. Identification and prioritization of barriers to the implementation of medical equipment marketing strategies using the AHP is implemented by [44]. Barriers to medical tourism in Turkey are identified and prioritized using the AHP in [45]. Barriers to the deployment of renewable-based mini-grids in Myanmar are prioritized using the AHP in [46].

However, despite the wide range of topics in which the AHP has been implemented, the present research study is the first attempt to implement it for the prioritization of sustainable urban mobility barriers.

2.2.1. Overview of the Analytic Hierarchy Process (AHP) and Delphi Method

The analytic hierarchy process (AHP) [47] is a multi-criteria analysis (MCA) method applied for the evaluation and prioritization of alternatives based on a set of criteria, which are weighted through the execution of pair-wise comparisons. In the context of AHP, the criteria are compared in pairs in regard to their contribution to the achievement of the overall goal of the decision problem and then the alternatives are compared in relation to each criterion concerning their preference degree. This way, a matrix of the relative importance of the compared elements is developed (Equation (1)), where \( n \) represents the number of elements of the same level.

\[
A = \begin{bmatrix}
   a_{11} & a_{12} & \ldots & a_{1n} \\
   a_{21} & a_{22} & \ldots & a_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
   a_{n1} & a_{n2} & \ldots & a_{nn}
\end{bmatrix}
\]
The pair-wise comparison is realized on the basis of a linear scale (Table 2), while the
normalization of the decision matrix follows by dividing each element by the sum of the
elements of the same column.

Table 2. Saaty’s scale for AHP pair-wise comparison.

| Intensity of Importance | Definition                                    |
|------------------------|-----------------------------------------------|
| 1                      | Equal importance                              |
| 3                      | Moderate importance of one over another       |
| 5                      | Essential or strong importance                |
| 7                      | Very strong importance                        |
| 9                      | Extreme importance                            |
| 2, 4, 6, 8             | Intermediate values between the two adjacent judgments |

Reciprocals

Table 3. Random consistency index (RI) values for n elements.

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

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

For the needs of the present research study, in Phase 2, the following steps of the
proposed Delphi-AHP methodology are implemented.

According to the above, within the framework of AHP, the evaluation of the sus-
tainable urban mobility barriers is realized through pair-wise comparisons and not on a,
e.g., 1 to 10 scale. The pair-wise comparison is considered to be preferable to the 1 to 10
rating as it seems to be easier for someone to answer if something is more important (and
how much more important) than something else rather than having to independently rate
something on a scale [48]. In other words, it seems to be easier to compare two things at a
time rather than to rate each one of them almost independently of the others, being obliged
to remember the value attributed to the ones already rated. Moreover, the consistency of
the answers concerning pair-wise comparisons can be easily checked using the consistency
ratio (CR) of the AHP. However, the main constraint of the AHP in this particular context is the restriction in the number of predominant barriers to be pair-wise-compared by the experts in an efficient way, allowing them to remain consistent given that the human mind is considered to be able to efficiently compare up to $7 \pm 2$ elements in pairs [49].

Concerning the Delphi method, it is an anonymous, multi-round, iterative survey process through which the opinion on a subject of each member of a group of people (engaged either because of expertise or because of position) is recorded [50]. The process can be completed after two or more rounds, with the questionnaire of the first round mainly including qualitative data. The responses recorded in the first round are synthesized and given back to the participants, aimed at the evaluation of the elements included in the study using various rating systems. There are various criteria for the completion of a Delphi method, with the establishment of a consensus threshold (usually between 50% and 97%) being the most common [50,51].

2.2.2. Steps of the Proposed Delphi-AHP Methodology

**Step 1:** Definition of the study area and overall description of its main sustainable mobility problems by the analyst(s).

**Step 2:** Selection of experts in the fields of transport and urban planning (researchers, planners, and policy officers) who have a deep knowledge of the study area and the corresponding sustainable mobility problems. A number of at least 10–15 participants—a total of 20 participants is considered sufficient when referring to a specific area—(referred to as first group hereinafter) is recommended for Step 3, while a number of 8–15 participants (referred as second group hereinafter) is recommended for group pair-wise comparisons of Step 4 [34,52]. The second group is a sub-group of the first group that comprises only professionals with a strong scientific background in transport planning. This choice is justified by the intention to minimize subjectivity in the pair-wise comparisons and the prioritization of the final list of barriers.

**Step 3:** Identification of sustainable urban mobility barriers for the study area.

**Step 3.1:** An initial list for the area under study is formed using the inventory of sustainable urban mobility barriers derived from the literature review (according to the above-described Phase 1 of the methodology in Section 2.1). Targeted interviews with a small number of representatives from the second group are conducted in order to form the initial list. The targeted interviews aim at the formulation of the most comprehensive list possible in order to facilitate the Delphi process of Step 3.2. In the context of the targeted interviews, the barriers from the inventory of Phase 1 that did not apply to the specific study area are removed. Moreover, other barriers that are unique for the study area are added.

As already mentioned in Section 2.1, the formulation of a common list of sustainable urban mobility barriers for all urban areas is not feasible. Thus, the aforementioned initial list of barriers is expected to be different for each urban area depending on its specific characteristics and special conditions in each period (e.g., COVID-19 effects). However, the starting point for the formulation of a city-specific list of barriers is the inventory of the urban mobility barriers of Table 1 (created on the basis of the relevant literature review).

**Step 3.2:** A modified Delphi is applied in order to highlight the most important barriers. More specifically, the initial list of Step 3.1 is delivered to the first group of experts in order for the most important barriers of the examined urban area to be selected. Each participant of the first group is asked to select the 10 most important barriers in her/his opinion. At the same time, each participant is asked to add any barrier that she/he believes should be among the 10 most important ones but is missing from the initial list. The exhaustiveness of the inventory of sustainable urban mobility barriers (Table 1), the careful elaboration of the targeted interviews, and the clarity and comprehensiveness of the initial list in Step 3.1 are very important in order to avoid omitting an important barrier from the initial list. The barriers selected by at least 50% of them form the final list to be included in Step 4. Given that the human mind is considered to be able to efficiently compare up to
7 ± 2 elements in pairs, it is recommended that the number of these barriers, which will be compared in pairs in Step 4, be in alignment with this principle [49].

A traditional Delphi survey consists of at least two rounds, as the first round usually refers to the qualitative data. A scale of 1–10 or a Likert scale is then usually adopted for the evaluation of the elements by the group of participants in the next rounds after the definition of the final list to evaluate. The way the modified Delphi is executed, as described above, allows for the completion even from the first round. In this way, time and resources are saved, as among the weaknesses of the traditional Delphi are the fact that it is considered time-consuming and effort-consuming (thus cost-consuming), while it is usually hard to achieve consensus [53–55]. The rating and prioritization of the elements is then realized through the execution of pair-wise comparisons according to AHP in the following step.

**Step 4:** Prioritization of sustainable urban mobility barriers based on AHP pair-wise comparisons.

**Step 4.1:** Pair-wise comparison of the barriers derived from Step 3.2 is conducted by the second group of participants according to the AHP methodology.

**Step 4.2:** Aggregation of the expert judgments by applying the “aggregation of individual judgments method” in order to attribute an average score to each barrier [52,56] is conducted. The use of the geometric, instead of the arithmetic, mean is recommended, as it is considered more stable and less influenced by extreme values, satisfying the “reciprocal property” [52,57,58].

**Step 4.3:** In using the expert judgements and geometric mean for each case as input data, the AHP decision matrix and the normalized (by dividing each element by the sum of the elements of the same column) AHP decision matrix are calculated. The barrier weights (priority vector W of Equation (2)) are finally extracted according to the AHP methodology. This specific step also involves the consistency control using Equation (3). By concluding this step, the prioritization of the city-specific sustainable urban mobility barriers is achieved.

It is recommended, as in most Delphi type and group decision-making approaches, that the survey and the pair-wise comparisons (Steps 3.2 and 4.1, respectively) are conducted anonymously in order to ensure equity and neutrality in the collection and treatment of data [34,50,52].

3. The City of Thessaloniki as a Case Study

3.1. Definition of the Study Area and Overall Description of Its Sustainable Mobility Problems

Thessaloniki is the second largest city in Greece with a population of more than 1,000,000 people in the wider metropolitan area. A unique feature of the city is its layout, as the central business district and the historical center develop along a narrow strip between the sea-front and a mountainous area (Figure 1). Furthermore, there are many monuments from different historical periods within the city’s boundaries. These features may affect the ability to implement certain interventions and measures of sustainable mobility, as indicated also by the inventory of sustainable urban mobility barriers (Table 1).
The first SUMP in Greece was completed for the metropolitan area of Thessaloniki in 2014 [59]. However, Thessaloniki still suffers from persistent sustainable urban mobility problems with negative impacts on traffic conditions, safety, and the shift towards public and active transport modes, accompanied with external impacts on the quality of the urban environment [60].

Mobility conditions are affected by illegally parked cars and motorcycles along pavements, bicycle lanes, and bus lanes, causing delays for motorized traffic and problems to active transport users. It should be highlighted that the municipal traffic police currently do not have enough resources to address the issue, while there is very limited initiative to change the mobility culture and choices of the citizens by “soft” measures such as awareness campaigns, school courses, seminars, etc.

It can be also observed that priority at signalized intersections is often given to motorized traffic over pedestrians and bicycles, causing delays and threatening the safety of vulnerable road users [60]. In addition, outdoor cafes and restaurants occupy a significant part of pedestrian infrastructure and, in combination with the aforementioned illegally parked vehicles, obstruct the seamless movement of pedestrians (especially those with reduced mobility or impairments). Moreover, open public spaces are scarce and poorly linked to each other by active transport networks.

Concerning cycling, the bicycle network, corresponding to 2.4% of the total road network (i.e., 12 km of bicycle lanes), does not provide continuity and spatial coverage of the whole city. The current legal and regulatory framework for micromobility is another potential barrier, which is currently addressed by the development of national regulations.

Regarding public transport, the public bus is the only available massive transport mode, operated by the Thessaloniki Urban Transport Organization since 1957. The construction of a metro system, which was initiated in 2003, is still ongoing. Its construction sites obstruct surface traffic due to the decrease of capacity of both roadways and pedestrian ways, while the adjacent land uses, local economic activity, and underground archaeological findings are also impacted.

Concerning the ongoing pandemic, in order to facilitate cycling and encourage social-distancing through sustainable mobility measures, as implemented in other cases worldwide [61], the local authorities decided in July 2020 to concede one of the lanes of the roadway along the sea-front to bicycle use without complementing this intervention with

![Figure 1. Thessaloniki’s metropolitan area.](image-url)
other measures. In a short period, it was observed that this may have led to the worsening of traffic congestion in the city center, as double-parked cars continue to occupy part of the remaining roadway capacity.

3.2. Selection of Participants in the Process of the Identification and Prioritization of Barriers

Following the proposed methodology, an initial list of sustainable urban mobility barriers, based on the inventory of sustainable urban mobility barriers (Table 1), was formed by performing a series of targeted interviews with four experts with great experience in the field of transport planning as well as a deep knowledge of Thessaloniki and its mobility problems. In addition to those, other experts (i.e., academics, researchers, planners, and policy officers) were selected to form a group of 20 experts. This first group of 20 experts participated in the Delphi survey for the identification of the most important barriers for Thessaloniki. The first group comprised of twelve academics, researchers, and practitioners with expertise in urban and transport planning, and eight policy officers in urban mobility working for the public sector (both administration and transport operators).

A total of 10 experts with the most extended experience in transport planning were short-listed from the first group in order to form the second group of experts. The second group participated in the pair-wise comparisons of the most important barriers for Thessaloniki in order to achieve their prioritization based on the AHP approach. The second group comprised exclusively of academics, researchers, and practitioners in order to ensure the scientific objectivity and avoid the subjectivity that may derive from political or other interests. All participants live and work in Thessaloniki, having a deep knowledge of its problems and specific needs.

3.3. Identification of Sustainable Urban Mobility Barriers

The inventory of sustainable urban mobility barriers (Table 1) was adjusted to the features of the study area based on the opinion of the involved experts (Step 3.1 of the methodology). After finalizing the list of barriers to be evaluated, the participants were asked to select the 10 most important ones. The final selection included the barriers that were selected by at least 50% of the participants (Step 3.2). These barriers, along with the percentage of participants selecting each barrier, are presented in Table 4.

Table 4. The predominant sustainable urban mobility barriers for Thessaloniki.

| Barrier Definition                                                                 | Code-Name | Percentage of Participants Selecting the Barrier (%) |
|-----------------------------------------------------------------------------------|-----------|-----------------------------------------------------|
| Decision-making is not based on scientific evidence and a holistic decision-aiding methodology that takes into account all of the parameters and stakeholder positions linked to the problem. | DM        | 80                                                  |
| The citizens’ level of education and awareness regarding the significance of sustainable urban mobility and sustainable transport modes are inadequate. | ED        | 65                                                  |
| There is a lack of effectively designed infrastructure for environmentally friendly mobility solutions, such as bicycle lanes and walkable areas. | IN        | 60                                                  |
| The behavior of drivers of motorized vehicles towards other road users and the use of public space are inappropriate, such as in the case of illegal parking and use of both dedicated lanes and pedestrian areas. | LB        | 60                                                  |
| There is a lack of effectively designed and managed public transport infrastructure (including the size of the fleet and the coverage, the use of environmentally friendly vehicles, and the organization of the network). | PT        | 60                                                  |
| There are no alternative and complementary public transport systems to the public bus. | CT        | 55                                                  |
| There is not enough cooperation between the authorities at the local, regional, and national level, and their coordination in decision-making is not efficient. | CO        | 50                                                  |
3.4. Prioritization of Sustainable Urban Mobility Barriers

In implementing Step 4 of the methodology, the pair-wise comparisons between the barriers of Table 4 were conducted by the participants, who were asked to respond to the question: “How important do you consider each barrier towards sustainable urban mobility in Thessaloniki compared to others?”. The task of each participant was to conduct a total of 21 pair-wise comparisons using the linear scale, as illustrated in Figure 2.

According to Step 4 of the proposed methodology, the “aggregation of individual judgments method” was applied in order to aggregate the expert judgments using the geometric mean (Step 4.2). These judgments, as well as the corresponding geometric mean (G.M.), are shown in Table 5. It should be highlighted that each participant (i) is represented by (EXPi), while each barrier is represented by the code-name provided in Table 4.

### Table 5. Expert judgments and geometric mean values regarding each pair-wise comparison.

| Barriers/Experts | EXP1 | EXP2 | EXP3 | EXP4 | EXP5 | EXP6 | EXP7 | EXP8 | EXP9 | EXP10 | G.M. |
|------------------|------|------|------|------|------|------|------|------|------|-------|-------|
| DM vs. ED        | 5    | 6    | 5    | 8    | 3    | 7    | 1/7  | 3    | 5    | 1/6   | 2.1356|
| DM vs. LB        | 7    | 4    | 1    | 9    | 4    | 5    | 1/9  | 4    | 1    | 1/8   | 1.5993|
| DM vs. IN        | 9    | 1/5  | 1/3  | 1/7  | 4    | 1/5  | 3    | 3    | 1/3  | 4     | 0.9839|
| DM vs. PT        | 8    | 1/5  | 1/3  | 1/7  | 3    | 1/5  | 3    | 4    | 1/5  | 3     | 0.9116|
| DM vs. CT        | 6    | 7    | 1/3  | 1/9  | 2    | 1/5  | 3    | 3    | 1/5  | 3     | 1.1063|
| DM vs. CO        | 9    | 4    | 7    | 1    | 1    | 5    | 6    | 2    | 1/3  | 5     | 2.3269|
| ED vs. LB        | 3    | 1/5  | 1/3  | 7    | 3    | 1/3  | 1/9  | 1/2  | 1/3  | 1/8   | 0.6202|
| ED vs. IN        | 5    | 1/7  | 1/5  | 1/9  | 2    | 1/7  | 7    | 1    | 1/5  | 7     | 0.7715|
| ED vs. PT        | 4    | 1/7  | 1/5  | 1/7  | 2    | 1/7  | 7    | 1/3  | 1/5  | 7     | 0.7056|
| ED vs. CT        | 3    | 1/3  | 1/5  | 1/9  | 2    | 1/7  | 7    | 1/3  | 1/5  | 7     | 0.7240|
| ED vs. CO        | 6    | 1/6  | 3    | 7    | 3    | 1/3  | 3    | 1    | 1    | 1     | 1.1760|
| LB vs. IN        | 5    | 1/5  | 1/3  | 1/9  | 1/3  | 1/5  | 9    | 1    | 1/7  | 7     | 0.7282|
| LB vs. PT        | 3    | 1/5  | 1/3  | 1/9  | 1/3  | 1/5  | 9    | 1    | 1/7  | 7     | 0.6978|
| LB vs. CT        | 4    | 4    | 1/5  | 1/9  | 1/2  | 1/5  | 9    | 1    | 1/7  | 7     | 0.9094|
| LB vs. CO        | 6    | 1/3  | 7    | 9    | 1/3  | 9    | 1    | 1/5  | 7    | 1.8481|
| IN vs. PT        | 1/4  | 1    | 1    | 1    | 1/2  | 1    | 1    | 1/4  | 1    | 1     | 0.7492|
| IN vs. CT        | 1/5  | 7    | 1/3  | 1    | 1    | 1    | 1    | 1/3  | 1    | 1     | 0.8564|
| IN vs. CO        | 1/3  | 5    | 7    | 9    | 1/2  | 7    | 1/6  | 1    | 5    | 1/5   | 1.4090|
| PT vs. CT        | 2    | 7    | 1/2  | 1/9  | 2    | 1    | 1    | 1    | 1    | 1     | 1.0375|
| PT vs. CO        | 4    | 5    | 7    | 1    | 1    | 7    | 1/6  | 1    | 5    | 1/3   | 1.8764|
| CT vs. CO        | 5    | 1/7  | 7    | 9    | 1/2  | 7    | 1/6  | 2    | 5    | 1/4   | 1.4172|

The calculated geometric mean values are used as input for the calculation of the AHP decision matrix (Equation (1)), as shown in Table 6. The normalized AHP decision matrix, shown in Table 7, is then calculated by dividing each element of the decision matrix by the
sum of the elements of the same column. The priority vector $W$ (Equation (2)), representing the barrier weights, and the result of the consistency control (Equations (3) and (4)) are also shown in Table 7.

Table 6. AHP decision matrix.

|     | DM   | ED   | LB   | IN   | PT   | CT   | CO   |
|-----|------|------|------|------|------|------|------|
| DM  | 1.0000 | 2.1356 | 1.5993 | 0.9839 | 0.9116 | 1.1063 | 2.3269 |
| ED  | 0.4683 | 1.0000 | 0.6202 | 0.7715 | 0.7056 | 0.7240 | 1.1760 |
| LB  | 0.6253 | 1.6123 | 1.0000 | 0.7282 | 0.6978 | 0.9094 | 1.8481 |
| IN  | 1.0164 | 1.2962 | 1.3733 | 1.0000 | 0.7492 | 0.8564 | 1.4090 |
| PT  | 1.0970 | 1.4172 | 1.4330 | 1.3348 | 1.0000 | 1.0375 | 1.8764 |
| CT  | 0.9039 | 1.3812 | 1.0996 | 1.1677 | 0.9639 | 1.0000 | 1.4172 |
| CO  | 0.4298 | 0.8503 | 0.5411 | 0.7097 | 0.5329 | 0.7056 | 1.0000 |

Table 7. Normalized AHP decision matrix, priority vector, and consistency control.

|     | DM   | ED   | LB   | IN   | PT   | CT   | CO   | W    |
|-----|------|------|------|------|------|------|------|------|
| DM  | 0.1805 | 0.2203 | 0.2086 | 0.1469 | 0.1639 | 0.1745 | 0.2105 | 0.1865 |
| ED  | 0.0845 | 0.1032 | 0.0809 | 0.1152 | 0.1269 | 0.1142 | 0.1064 | 0.1045 |
| LB  | 0.1129 | 0.1663 | 0.1304 | 0.1088 | 0.1255 | 0.1435 | 0.1672 | 0.1364 |
| IN  | 0.1834 | 0.1337 | 0.1791 | 0.1493 | 0.1349 | 0.1351 | 0.1275 | 0.1490 |
| PT  | 0.1980 | 0.1462 | 0.1869 | 0.1994 | 0.1798 | 0.1637 | 0.1698 | 0.1777 |
| CT  | 0.1631 | 0.1425 | 0.1434 | 0.1744 | 0.1733 | 0.1577 | 0.1282 | 0.1547 |
| CO  | 0.0776 | 0.0877 | 0.0706 | 0.1060 | 0.0958 | 0.1113 | 0.0905 | 0.0914 |

$\lambda_{max} = 7.0672$  
$CI = 0.0112$  
$CR = 0.0085 < 0.10$

4. Results and Discussion

The sustainable urban mobility barriers for the city of Thessaloniki, Greece, according to the weights (priority vector $W$ of Table 7) that were calculated by implementing the proposed modified Delphi-AHP methodology are presented in Figure 3.

According to Figure 3, the most important barrier to sustainable mobility in the city is that “decision-making is not based on scientific evidence and a holistic decision-aiding methodology that takes into account all parameters and stakeholders’ positions linked to the problem (DM)”.

The aspect of public transport was also recognized by experts as a main issue, with the barriers regarding the “lack of effectively designed and managed public transport infrastructure (including the size of the fleet and the coverage, the use of environmentally friendly vehicles and the organization of the network) (PT)” and the absence of “alternative and complementary public transport systems to the public bus (CT)” scoring next in the ranking. The “lack of effectively designed infrastructure for environmentally friendly mobility solutions, such as bicycle lanes and walkable areas (IN)” was close to the score of the aforementioned barrier regarding the absence of alternative public transport systems. The inappropriate behavior of “drivers of motorized vehicles towards other road users and the use of public space is inappropriate, such as in the case of illegal parking and use of dedicated lanes and pedestrian areas (LB)” as well as the issue of inefficient coordination and “cooperation between the authorities at local, regional and national level (CO)” were the barriers that accumulated the lowest weights.
It should be highlighted that apart from the current research study, the only available recent study that aimed to prioritize the problems in urban mobility for the city is the main deliverable of the Sustainable Urban Mobility Plan of Thessaloniki [62]. In this report, the contractor of the SUMP conducted a questionnaire survey with the participation of the citizens of the municipality of Thessaloniki. In the survey, the citizens were asked to rank according to significance and using a scale from 1 to 9 the main problems of mobility in the city. According to the survey, the top-ranking problems were:

1. the insufficient pedestrian network;
2. the problematic and inadequate public transport system;
3. the insufficient parking management in the city center;
4. the poorly designed bicycle network for the pedestrian network;
5. the traffic congestion during peak periods;
6. the inability to adopt innovative mobility solutions;
7. the limited traffic safety;
8. the insufficient organization of urban freight transport; and
9. the inability to cope with the seasonal fluctuations of transport demand (e.g., during the international expo).

The specific survey differentiates from the methodology proposed by the current research study due to three main reasons. Firstly, the aforementioned survey is targeted to citizens, while the current research study proposes and tests a methodology based on international reviews and expert judgements. Secondly, the problems identified and ranked by the SUMP cannot be considered solely as barriers because some of them refer to the result of barriers. For example, the traffic congestion during peak periods, inability to adopt innovative mobility solutions, inability to cope with seasonal fluctuations of demand, and limited traffic safety may be the result from the interaction of budget constraints, data unavailability, poor organization, transport behavior, city particularities, and other categories of barriers, as presented in Table 1. Thirdly, barriers stemming from administrative and political aspects or behavioral issues are missing from the questionnaire survey. Nonetheless, both studies highlight barriers related to the inefficiency of the public transport, cycling, and pedestrian networks in Thessaloniki.
5. Conclusions

The present research study aims to support policy-making by proposing a methodology that identifies and prioritizes the sustainable mobility barriers for a specific urban area. Towards this purpose, this work provides, in the first phase, a comprehensive inventory of barriers based on a literature review. In the second phase, this inventory is further adapted to the conditions of an urban area and the sustainable mobility barriers for this area are both evaluated and prioritized through a modified Delphi-AHP approach. It should be mentioned that it is the first time this approach has been implemented within the specific scope.

Given that the comprehension of a problem and of its parameters constitutes a fundamental precondition for its solution, the identification and prioritization of the most important sustainable urban mobility barriers through an “individualized” approach for each area are prerequisites for the development and implementation of effective policies. The main advantages of the proposed methodology are its adaptability to the context of any urban area, regardless of its characteristics; the combination of findings from international literature with local knowledge and experience; and the extraction of comparative results regarding the relative importance of the examined barriers. The added value of the methodology is the ability to integrate the SUMP approach by ensuring a scientific basis in the analysis of Step 3 of SUMP: “Analyze Mobility Situation”.

The methodology was tested through the case study of Thessaloniki, Greece, confirming its applicability and advantages against a challenging environment with many persistent barriers towards sustainable urban mobility. In close relevance to the scope of the present research study, the case-study highlights, as the most important barrier, the lack of a scientifically based, holistic methodology to support the decision-making process. Next to this, the deficiencies in public and active transport infrastructure are considered very important. The behavioral aspect, especially regarding drivers, is considered less important by experts, a finding that was somewhat unexpected due to the observed negative impact of illegal parking to the overall mobility conditions in the city. The issue of integrated governance at the local, regional, and national level was considered important but ranked lower in the list, possibly due to the more urgent character of the other barriers.

The proposed methodology can be further evolved in the future in order to analyze, evaluate, and select the most suitable sustainable mobility policies against the most important sustainable mobility barriers of any given city. The set of the alternative policies can be based on the results of the present research study and thus directly relate the most important barriers. In order to achieve the evaluation and prioritization of these alternative policies, a multi-criteria analysis can be executed with the participation of local experts and stakeholders. Moreover, another direction for future research would be the comparative analysis between citizens’ perceptions (through public consultation) and experts’ choices in the identification of the most important barriers for a specific city.

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