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Systematic Review

Combining Resilience and Sustainability in Urban Mobility: A Scoping Review and Thematic Analysis

Mariana Luiza da Silva Sassaron [1,*], Antônio Nélson Rodrigues da Silva [1], Fernando Fonseca [2,*], Daniel Rodrigues [2], Paulo J. G. Ribeiro [2] and Camila Mayumi Nakata-Osaki [3]

1 Department of Transportation Engineering, São Carlos School of Engineering, University of São Paulo (EESC-USP), São Carlos 13566-590, Brazil; anelson@sc.usp.br
2 Centre for Territory, Environment and Construction (CTAC), University of Minho, 4800-058 Guimarães, Portugal; dsr@civil.uminho.pt (D.R.); pauloribeiro@civil.uminho.pt (P.J.G.R.)
3 USCS Polytechnic School, Conceição Campus, Municipal University of São Caetano do Sul, São Caetano do Sul 09530-060, Brazil; camila.osaki@online.uscs.edu.br
* Correspondence: msassaron@usp.br (M.L.d.S.S.); ffonseca@civil.uminho.pt (F.F.)

Abstract

The need to address long-term sustainability goals while ensuring short-term resilience to unexpected disruptions is placing an increasing challenge on urban mobility systems. This study organizes an analytical framework that compares and integrates the concepts of sustainability and resilience in urban mobility. A scoping review and thematic analysis were conducted to identify and compare the definitions, dimensions, and operational features of these two paradigms. The results reveal that, although they are conceptually distinct, sustainability and resilience share subjects of analysis, including multimodality and diversity of transport modes, the impacts of climate change, and social equity issues. However, they also present tensions between the dimensions of efficiency and redundancy, speed of recovery and sustainability of implemented solutions, and new vulnerabilities introduced by sustainable technologies. These synergies and trade-offs underscore the necessity of an integrated, systemic and holistic approach to urban mobility planning. The study emphasizes that building resilient and sustainable urban mobility requires coherent policies across government levels, technical capacity, public engagement, and comprehensive indicators. Recommendations for future research include developing integrated metrics and planning tools to support evidence-based decision-making.

Keywords: urban mobility; resilience; sustainability; integrated planning

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1. Introduction

1.1. Urbanization Challenges and the Role of Sustainability and Resilience

Driven by the process of urbanization, urban environments are growing in size and complexity, posing social, environmental, and economic challenges of unprecedented scale and scope [1]. Increasing environmental threats, such as major storms, severe droughts, food shortages, heat waves and fires, introduce greater uncertainty into the future of urban centers, putting pressure on institutions to ensure a future with quality of life and resilience to the impacts of adverse events on society [1,2]. In this scenario, urban systems face increasing challenges in maintaining adequate levels of operations and services. This includes the transportation system, which is essential to ensure urban mobility and the functioning of the society [3–5], but is often exposed to natural and anthropogenic risks and is characterized by high vulnerability and low adaptability [6–8]. This reality requires a holistic analysis of the city, capable of understanding its problems, aligning priorities and objectives, and planning more effective policies and governance strategies for the future [9]. A holistic approach involves considering the system as an interconnected whole, emphasizing the broader picture rather than isolated parts. In this sense, holistic strategic planning treats all components of the process as integrated and interdependent elements of a single system [10].

To improve urban systems, societal well-being, and environmental quality, researchers have combined the concepts and approaches of sustainability and resilience to guide urban planning [7,9,11–17]. Sustainability, in the urban context, refers to the ability of the city to develop in a way that balances social, economic, and environmental needs and ensures the quality of life for the present without compromising future generations [18]. Resilience, on the other hand, addresses the ability of urban systems to reduce the impact of disruptions and maintain operational continuity. It is characterized by the ability to adapt, recover, resist, and transform in the presence of disturbances [19]. As both concepts are complex and prominent, efforts to implement them together must be carefully studied to understand their similarities and differences and ensure effective applications [2,9].

The urban mobility system directly influences society's quality of life and its economic and social development by ensuring accessibility to commercial, educational, work, cultural, and recreational destinations. In light of the need for a holistic approach to urban systems, this study contributes to the field by identifying research gaps and organizing a structured analytical framework that integrates resilience and sustainability in urban mobility. The framework examines how these concepts interact, highlighting overlaps (shared aspects), synergies (mutually reinforcing effects), and tensions (potential conflicts or trade-offs), thereby addressing environmental, social, and institutional challenges as interconnected components of the system. The following subsection elaborates on research gaps at the intersection of sustainability and resilience in urban mobility and highlights issues that require further attention.

1.2. Research Gaps at the Intersection of Sustainability and Resilience in Urban Mobility

Transportation systems are fundamental to economic development and the improvement of societal well-being, as they ensure urban mobility and connectivity [6,20,21]. These systems affect the economic prosperity, urban growth, tourism dynamics, and equity promotion within cities [7]. However, given the continuous sprawl and urban growth, as well as the increase in territorial complexity and urban population [22], the transport system has become more vulnerable to extreme events [23,24].

Considering these challenges, the concepts of resilience and sustainability have gained prominence in the academic and policy arenas for guiding contemporary urbanization processes [9,12,25].

Sustainable urban mobility is based on the idea of development that meets the needs of the present without compromising the ability of future generations to meet their own needs, analyzing the environmental, social, and economic impacts of the transportation system. It is a strategy that allows transport to fulfill its economic and social role, while at the same time limiting its negative impact on the environment [26,27]. Sustainable mobility is an alternative approach to transport planning that encompasses accessibility, prioritization of active and public transportation modes, reduction in travel distance, and incentives for greater transportation system efficiency [28].

Resilience of urban transportation systems is defined as the ability of a system to resist and absorb the effects of a disturbance, natural or man-made, maintaining an acceptable level of service, and recovering or transforming itself within a reasonable time and cost. The main characteristics are robustness, preparedness, rapidity, adaptation, and redundancy [23].

The two concepts have been used in different ways in recent years, with some authors linking them as the same concept and others claiming that they are completely different and unrelated concepts. For example, some argue that the conservation goals of sustainability are not aligned with the adaptive goals of resilience. Davidson et al. [16] address the issue by presenting resilience as a component of sustainability, while Saxena et al. [15] conclude that sustainability is presented as a tool to achieve resilience. The terms in question refer to the state of a system or its characteristics over time. However, they have different applications at spatial and temporal scales. Specifically, resilience prioritizes processes, while sustainability prioritizes outcomes [2,11,20].

According to Marchese et al. [2], both concepts are organized in the literature in three ways: (1) resilience as a component of sustainability, (2) sustainability as a component of resilience, and (3) resilience and sustainability as separate goals. The first perspective suggests that enhancing resilience strengthens a system's sustainability, whereas improving sustainability alone may not inherently increase resilience. Resilience would be a means to achieve lasting sustainability. The second perspective considers resilience the ultimate goal of the system, with sustainability as a contributing factor. In this view, increasing sustainability increases resilience, but increasing resilience doesn't increase sustainability. The third perspective describes the terms as concepts with different goals that can either complement or compete with each other. This perspective is primarily found in the fields of civil infrastructure, urban planning, and public policy [2].

Nakata-Osaki & Rodrigues da Silva [3] discuss these concepts in the context of urban mobility. According to the authors, sustainable mobility systems tend to be more resilient because they incorporate multiple modes of transportation instead of relying on one mode. Moreover, sustainable mobility systems increase permeable areas by integrating green infrastructure, such as parks and green spaces. They reduce emissions and dependence on fossil fuels by encouraging low-carbon modes, like public transportation, cycling, and walking. Sustainable mobility systems also enhance social inclusion and increase cohesion and collective capacity to respond to crises by prioritizing accessibility for all users, thereby enhancing robustness and adaptability. However, to better apply these concepts to urban mobility, it is necessary to understand their mutual influence on transport systems, whether they are complementary or competitive, unique or components of each other. For example, is sustainable urban mobility automatically resilient? If resilience in mobility is achieved, is it achieved in a sustainable way? And to answer these questions, it is necessary to assess sustainability and resilience [29].

Several tools have been developed to assess sustainable urban mobility [30–36]. One tool of particular interest is the Index of Sustainable Urban Mobility (I_SUM), developed in the scientific context by Costa [31] and later used as the basis for other indices [37,38]. The index is organized into nine domains, 37 themes, and 87 indicators, and it is based on an extensive literature review and field research. Similarly, methodologies for assessing the resilience of transportation systems have been proposed in the literature, with indicators and metrics that vary according to the perspective, objective, and scope of the analysis, ranging from qualitative to quantitative methods [6]. Methods for assessing resilience in transportation can be specific to a type of disaster, such as flooding [39–42], to a mode of transportation, such as metro [43–45], or general, related to resilience characteristics [23,46,47]. The choice of indicators is fundamental for assessing resilience and depends on the available data, processing resources, the stage of concern and the scale considered [48].

Although numerous models have been proposed, identifying indicators and metrics that effectively capture the complexity of applying resilience and sustainability simultaneously—while accounting for their interdependencies—remains a significant challenge. The literature still lacks comprehensive frameworks that address the potential trade-offs inherent in the joint implementation of these concepts. Few studies explore whether pursuing sustainability may compromise resilience, or vice versa, and how integrated planning strategies can be designed to maximize the benefits of both concepts. Therefore, the integration of framework and metrics is a research gap at the intersection of sustainability and resilience [29,49] (Figure 1—box 1).

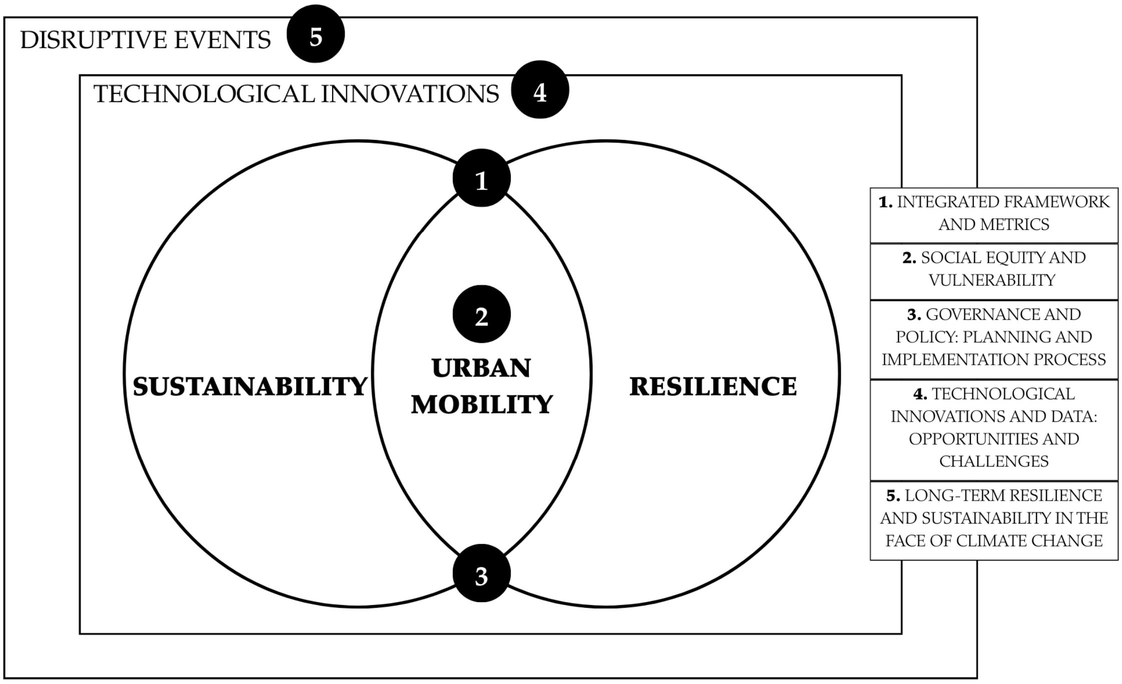

Figure 1. Conceptual diagram of the five primary research gaps at the intersection of urban mobility sustainability and resilience. Note: Gaps (1) and (3) are located at the intersections, highlighting areas that require managing synergies and trade-offs. Gap (2) is positioned at the heart of the integration. Additionally, two contextual layers (gaps (4) and (5)) frame the entire system.

To visually summarize the challenges identified in the literature regarding the integration of sustainability and resilience, Figure 1 presents a conceptual diagram of the five main research gaps. The diagram positions urban mobility as the core area of integration between the concepts. The placement of each numbered gap illustrates its specific relationship with these concepts. Gaps requiring direct integration between the two domains, (1) Integrated Framework and Metrics and (3) Governance and Policy, are situated on the boundaries of the overlapping circles. At the middle of this overlap lies (2) Social Equity and Vulnerability, representing a foundational issue for any unified approach. Finally, the entire system is influenced by two broader contexts, represented by the outer boxes: the opportunities and challenges of (4) Technological Innovations and Data, and the increasing frequency of (5) Disruptive Events, such as climate change. The four gaps not yet discussed (2 to 5) are presented below.

Another important aspect of promoting urban mobility is addressing the disparities among different regions of the city. Due to its extensive spatial coverage, the transport system is embedded in diverse social, economic, and infrastructural contexts across the city. Central areas tend to be more exposed to disruptive events due to higher passenger densities, infrastructure that facilitates the propagation of incidents, and the presence of congestion—a major issue during emergencies. However, these areas often exhibit a higher level of resilience due to their designation as "priority zones" for disaster response and recovery, which is complemented by their higher accessibility to diverse modes of transportation, resulting in greater redundancy. In contrast, peripheral areas, characterized by reduced accessibility, show reduced resilience [50].

Santos et al. [51] conducted an analysis of the resilience and vulnerability of public transportation systems to economic and social threats. The authors emphasize the role of the dichotomous relationship between economic growth and sustainable urban development in generating socio-economic inequality, particularly in developing countries. Their findings indicate high levels of vulnerability in areas marked by negative socio-economic indicators, while central areas tend to exhibit greater resilience. According to Zhang et al. [52], existing inequity can compromise the sustainability and stability of transport services.

The impact of extreme events, whether man-made or natural, on various regions of the city is not uniform, resulting in disproportionate effects on the population [50–52]. Social inequality, along with urban segregation and infrastructure disparities, presents significant challenges that the transportation systems must overcome to ensure equitable access to urban mobility to all citizens. Therefore, it is essential to fully understand these unequal impacts and to develop strategies that guarantee fair and inclusive access to mobility, both under normal circumstances and during periods of disruption. The lack of integrated approaches addressing social equity and urban disparities in the context of urban mobility can be identified as another gap in the literature (Figure 1—box 2).

When exploring urban planning, it is important to address policy instruments and governance structures. A relevant issue concerns the implementation, promotion, and maintenance of the concepts and actions under discussion. Holden et al. [53], in their analysis of sustainable mobility, highlight the main agents for achieving it: public actors (politicians and bureaucrats), civic actors (people), and private actors (firms). They emphasize the necessity of collaborative efforts, in which all actors contribute at all levels by forming alliances and aligning interests. Resilience is no different; it involves a wide range of activities, actors, and actions that need to be guided, planned, and communicated [54]. Therefore, it is essential to develop policy instruments that support resilience [55,56] and sustainability [26,57] and evaluate the effectiveness of actions aiming at promoting, implementing, and maintaining them. Effective governance and policy frameworks are essential for promoting resilient and sustainable urban mobility. Accordingly, further research is needed on how to implement both resilience and sustainability simultaneously in urban mobility planning, engaging stakeholders and coordinating efforts across distinct levels (Figure 1—box 3).

Beyond institutional and governance challenges, technological innovation and the strategic use of data represent another key dimension in promoting resilient and sustainable urban mobility. The increasing digitalization presents opportunities to enhance resilience through real-time monitoring, greater adaptive control, and information sharing [58]. Furthermore, data plays a critical role in planning and in supporting the decision-making process during both the development and ongoing management [59–61]. Moreover, connected and automated vehicles, electric vehicles, shared mobility solutions and intelligent transportation systems (ITS), are technological innovations that are regarded as pivotal components of the future transportation systems [62–64]. Electric vehicles, for example, are an important step in the transition from fossil fuels to less polluting energy sources [64]. However, these technologies introduce new vulnerabilities, such as cyber-attacks and data breaches, which require further investigation to better understand the associated risks and opportunities [48,65]. The cyber domain poses unique challenges to transportation networks [62], but it also presents significant potential for innovation. Technological advancements directly influence on both sustainability and resilience by expanding urban mobility datasets and supporting more efficient planning and operation of transport systems. A significant research gap lies in the development of robust methodologies for efficiently analyzing these data, the addressing of emerging threats, and the assurance of user security, safety, and privacy in increasingly digitalized mobility ecosystems [65] (Figure 1—box 4).

Urban mobility systems typically evolve gradually, but this dynamic can shift rapidly in the face of large-scale emergency events, such as natural disasters [61]. Environmental issues directly impact mobility patterns and travel behavior, adding complexity to urban mobility system dynamics [66–68]. The effects of climate change, including heavy rains and snowfalls, heat waves and fires, have been demonstrated to affect travel costs, increase travel time, and reduce mobility, which in turn impacts population well-being [69,70]. For instance, Zhang et al. [68] examined travel-related heat exposure and demonstrated that the distribution of urban infrastructure significantly influences exposure levels. Therefore, it is crucial to prepare cities for these changes by building climate resilience and promoting innovative solutions for sustainable urban living [69,71]. However, climate change not only challenges urban systems, but also affects the effectiveness and performance of sustainability and resilience solutions themselves [72]. This underscores the necessity for long-term frameworks that assess not only how mobility systems respond to climate change, but also how resilient and sustainable solutions themselves can adapt over time (Figure 1—box 5).

In summary, the literature shows that, although sustainability and resilience are increasingly recognized as essential for urban mobility, their integration remains underdeveloped. Five priority areas emerge at the intersection of the two concepts: (1) the need for integrated frameworks and metrics that enable both concepts to be assessed together; (2) the role of social equity and vulnerability as core aspects of urban mobility that directly influence sustainable and resilient outcomes; (3) governance and policy challenges, particularly in relation to planning and implementation processes that must integrate both perspectives simultaneously; (4) technological innovations and the expanding use of data, which offer significant opportunities but also raise critical challenges; and (5) long-term resilience and sustainability in the face of climate change, where disruptive events emphasize the urgency of strategies that enable urban systems to adapt and endure over time.

Together, these gaps define a research agenda emphasizing the need for comprehensive approaches connecting both theoretical and practical perspectives. These gaps have a particularly significant impact in developing regions, where social inequality exacerbates spatial vulnerability, and where there is a lack of policy instruments for planning and decision-making and slow adoption of technological innovations.

Among these, the absence of integrated metrics and assessment frameworks is concerning because it impacts the ability to comprehensively and coherently diagnose, compare, and guide urban mobility systems. This study addresses this issue by adopting a macro-level perspective. We argue that before a robust, testable integrated metric can be constructed, it is essential to first map the conceptual landscape by identifying the synergies, tensions, and overlaps between sustainability and resilience. Accordingly, the analytical framework developed here serves as the necessary groundwork for future research to create such quantitative tools.

To this end, a scoping review was conducted to structure a framework for characterizing resilience in urban mobility. This framework was then compared with the I_SUM [31], in order to identify the relationships between the domains and characteristics of both. Resilience in urban mobility is still an emerging field; therefore, a scoping review was appropriate to capture the breadth of definitions, dimensions, and characteristics. In contrast, sustainability in urban mobility already has well-established frameworks, such as those developed by Costa [31], Banister [28], Jeon and Amekudzi [33] and Holden et al. [27], which synthesizes extensive bibliographic and empirical research. By first analyzing the two concepts separately, we ensure that their core principles were not diluted. The subsequent comparison through a thematic analysis was designed to highlight both synergies and tensions, allowing integration without loss of meaning.

The main contributions of the paper are:

(1) Identification of five priority areas emerging at the intersection of resilience and sustainability in urban mobility.
(2) Review of the literature to structure a framework for resilient urban mobility, including definitions, dimensions, key characteristics, and actions.
(3) Development of an integrated analytical framework that compares and combines the concepts of sustainability and resilience in urban mobility, providing a basis for the development of integrated metrics.
(4) Mapping of similarities, shared themes, and synergies that highlight opportunities for integrated planning strategies.
(5) Identification of conflicts and trade-offs that must be carefully considered.
(6) Recommendations for future research directions and planning tools to support sustainable and resilient mobility.

2. Materials and Methods

The methodology of this study is structured into three main stages. The first stage aims to structure a conceptual framework for urban mobility resilience, starting from a scoping review. The second addresses and seeks to justify the use of Index of Sustainable Urban Mobility (I_SUM) as a sustainability framework. The third consists of comparing this structure with an existing framework for sustainable urban mobility to identify intersections, divergences, and potential integration strategies.

2.1. Framework of Resilience of Urban Mobility

Given the exploratory nature of the research and the intention to map the conceptual boundaries of the topic, a scoping review was considered an appropriate approach. The objective was to identify studies addressing resilience in urban mobility systems and collect key concepts, definitions, and characteristics. Scoping reviews are especially useful for clarifying definitions and synthesizing evidence, especially when addressing a broad research question [73]. According to Munn et al. [74], a scoping review is preferable to a systematic review when the authors wish to identify characteristics and concepts and provide an overview of the evidence rather than answer a specific question. Like a systematic review, a scoping review protocol predefines the objectives and methods [73]. The eligibility criteria, information sources, and search strategy must be clearly presented in the text [75].

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [73,75] guided the structuring of the framework for urban mobility resilience. A scoping review protocol to guide the execution of the review was developed and uploaded to Open Science Framework (https://osf.io/jse3b/, accessed on 11 October 2025) in October 2025. The PRISMA-ScR Checklist is presented in Supplementary Materials.

In this study, the research question was, "What is the definition, dimensions, and characteristics of urban mobility resilience?". The adopted strategy is outlined below.

2.1.1. Search Strategy and Search Terms

The search was conducted in two academic databases, Web of Science (WOS) and Scopus, in February 2025. It was limited to journal articles published in English over the last ten years, including articles from the current year, covering the period from 2014 to 2025. The search was configured to look for occurrences of the term in the title, abstract and keywords fields to minimize the risk of overlooking relevant studies. The following search string was applied:

- "mobility resilien*" OR "transport* resilien*" OR "transport* system* resilien*" OR "transport* network* resilien*" OR "resilien* of urban transport*" OR "resilien* in urban mobility" OR "resilien* in transport*" OR "resilien* of transport*" OR "resilien* in mobility".

Quotation marks were used to specify exact phrases, the Boolean operator "OR" to broaden the scope, and the truncation symbol "*" to capture different word endings. This strategy aimed to identify studies that explore resilience in urban mobility systems from diverse conceptual and methodological perspectives.

2.1.2. Selection of Sources of Evidence

The results from both databases were merged and duplicate records were removed. Then, titles and abstracts were screened to identify studies aligned with the research objective. Articles that did not focus on mobility or transportation systems were excluded. Additionally, studies addressing only the resilience of specific structures, such as bridges or tunnels, without considering the broader urban mobility system, as well as studies focusing exclusively on freight transport, were excluded. Before assessing the articles that were not deleted for eligibility based on a full reading of the text, a new set of studies were considered.

2.1.3. Scientometric Review

To complement the preliminary set of studies and increase the likelihood of capturing key contributions in the field, a scientometric review was also conducted. Scientometric analysis is a quantitative approach to evaluate scientific publications within a specific field. This method enables researchers to trace the development of an area and visualize its knowledge domains [76]. This strategy is especially beneficial for identifying the most representative publications, which can serve as valuable sources for conducting a systematic review [77].

In this case, the search data were obtained from the Web of Science (WOS) academic database in March 2025. It was limited to journal articles and conference proceeding papers published in English, with no restrictions regarding publication year. The search was configured to retrieve results only from the keywords field, as previous broader configurations—such as including title and abstract—resulted in many studies that were not aligned with the objectives of this research. The following search string was applied:

- ("resilien*" OR "robustness" OR "recover*" OR "vulnerab*" OR "redundancy" OR "reliability") AND ("urban mobility" OR "urban transport*" OR "transport* system*" OR "transport* networks" OR "public transport*" OR "passenger mobility")

The Boolean operator "OR" was employed to expand the range of terms referring to similar or related concepts, while the operator "AND" ensured that the results addressed both resilience-related aspects and urban mobility. The truncation symbol "*" was used to capture different word endings. This strategy aimed to obtain a more extensive set of studies; therefore, quotation marks were not applied.

Then, the results from the search were exported from the database as a plain text file containing all records content and subsequently imported into Biblioshiny. Biblioshiny is an app that provides a web-interface for the Bibliometrix R Package version 4.3.2, an open-source tool programmed in the R language for conducting quantitative research in scientometrics and bibliometrics. The package supports data loading and converting, data analysis and data visualization [78]. As this article does not aim to conduct a complete scientometric analysis, only the "Most Global Cited Documents" function in Biblioshiny was used. The Normalized Total Citations (NTC), calculated by dividing the total number of citations of an article by the average number of citations of all documents published in the same year [79], was used to select the top 50 articles. The title and abstract of these articles were screened, and those aligned with the objectives of this study were included in the set of selected works.

2.1.4. Data Synthesis

The studies identified through scientometric analysis were merged with those initially selected in the scoping review, and duplicate records were removed. Then, the full-text articles were assessed for eligibility, and the final set of studies to be included in the review was determined. Articles without full text, specific case studies that did not contribute to the objective of this review, and articles without definitions or characteristics of resilience in urban mobility or transportation systems were excluded. Finally, the remaining articles were analyzed, and information regarding definitions, characteristics, and related concepts of urban mobility resilience was collected. Figure 2 shows the number of studies and the step-by-step procedure. Table 1 presents all the studies selected. The definitions of resilience presented in the select studies were organized in Table 2. The characteristics and related concepts are developed throughout the results section.

It is important to emphasize that the conceptual framework constructed is predominantly grounded in the research conducted by Gonçalves & Ribeiro [23], who examined the resilience of transportation systems, and Ribeiro & Gonçalves [19], who explored the concept of urban resilience.

2.2. Framework of Sustainable Urban Mobility

Given the existence of comprehensive studies on sustainable urban mobility, this study adopts the Index of Sustainable Urban Mobility as a sustainability framework. Costa [31] defines I_SUM as a tool for evaluating and monitoring urban mobility. It has the capacity to reveal current conditions and assess the impact of measures and strategies aimed at sustainable mobility. The index is important to support urban public administration and management of mobility and public policy formulation [31,80,81], and it has been identified as the most commonly used index to assess sustainability in urban mobility [80]. During the research process, additional indicators were examined [82]; however, Costa's indicators were ultimately identified as the most suitable due to their comprehensive scope and stronger alignment with the priority themes of this study.

I_SUM is a straightforward instrument with the capacity to adapt to local conditions [31,80,81]. Over the last years, the index has been applied by numerous authors in diverse case studies [80,81,83–86] and has been recommended for the monitoring of the results of public policies and mobility planning [87].

The index was developed through an extensive literature review and field research, drawing upon concepts and elements identified by technicians and managers working at urban and transportation planning agencies or metropolitan regions [31,81]. These elements reflect the most pertinent issues for mobility planning from a practical standpoint. I_SUM is a multifaceted evaluation instrument that comprehensively addresses the three fundamental sustainability dimensions: social, environmental, and economic. It employs a structured hierarchy comprising nine domains, thirty-seven themes, and eighty-seven indicators, offering a systematic approach to assessing sustainability.

The structured and multidimensional design of the index allows for a comprehensive examination of sustainability in urban mobility systems, making it particularly suitable for comparative analysis with the resilience framework developed in this study.

2.3. Comparing the Concepts of Sustainability and Resilience in Mobility

This study employs Thematic Analysis, proposed by Braun & Clarke [88], a qualitative research method used to identify, analyze, and report patterns (themes) within a dataset. Although traditionally associated with the social sciences and psychology, its flexibility and methodological rigor have made it a valuable tool for analyzing texts and concepts, and it has also been applied in studies related to urban mobility [89–91]. Its suitability for this research lies in its capacity to perform a systematic and in-depth comparison of conceptual frameworks, moving beyond a superficial examination of their components. The method allows for the deconstruction and subsequent regrouping of the theoretical and operational foundations of each concept, making it ideal for identifying the synergies, tensions, and overlaps between sustainability and resilience in urban mobility.

The analytical process was conducted following the six structured phases proposed by Braun & Clarke [88], using the components of (I_SUM) [31] and the resilient urban mobility framework developed in Section 2.1 as the "data". The phases were:

(1) Familiarization with the data: in-depth reading of the objectives, dimensions, and indicators of each framework.
(2) Generating initial codes: systematically extracting relevant conceptual units.
(3) Searching for themes: grouping codes into potential themes that reflected the structure of both concepts.
(4) Reviewing themes: refine them and ensure they accurately represented the data.
(5) Defining and naming themes: establish the final comparative architecture.
(6) Producing the report: organizing the findings.

To validate the analysis and ensure its reliability, a researcher developed the themes and then had other researchers review them to verify the coherence and logic of the categorization. The results were organized into thematic matrices to facilitate a systematic comparison.

3. Results

The results are organized following the structure presented in Section 3. The first subsection presents the findings from the scoping review, including the characteristics of the selected sources and the development of the analytical framework. The second subsection reports the results of the thematic analysis, including the comparison between frameworks and the identification of synergies and tensions between the concepts of sustainability and resilience in urban mobility.

3.1. Resilient Urban Mobility Framework Development

Figure 2 presents the number of studies identified through database searches and scientometric review, as well as those screened, assessed for eligibility, and included in the final review. A total of 441 studies, after duplicates removed, were initially screened by title and abstract. Of these, 283 were excluded for not addressing resilience in transportation or urban mobility, for focusing on freight transport, or for analyzing isolated infrastructure elements (e.g., bridges). The remaining 158 studies were assessed for full-text eligibility, and 113 were excluded for not presenting definitions, concepts, or characteristics relevant to this study. The final sample comprised 45 studies, published between 2015 and 2025, with a notable concentration in recent years (7 in 2023 and 8 in 2024).

Table 1 presents the articles included in the review. The studies focus on several interrelated themes: conceptualization of resilience [23,48,50,92–99]; assessment and measurement methodologies [13,21,24,100–110]; impacts of hazards and disturbances [7,8,55,95,111–116]; and enhancement strategies and planning [5,21,55,58,65,105,113,117–123].

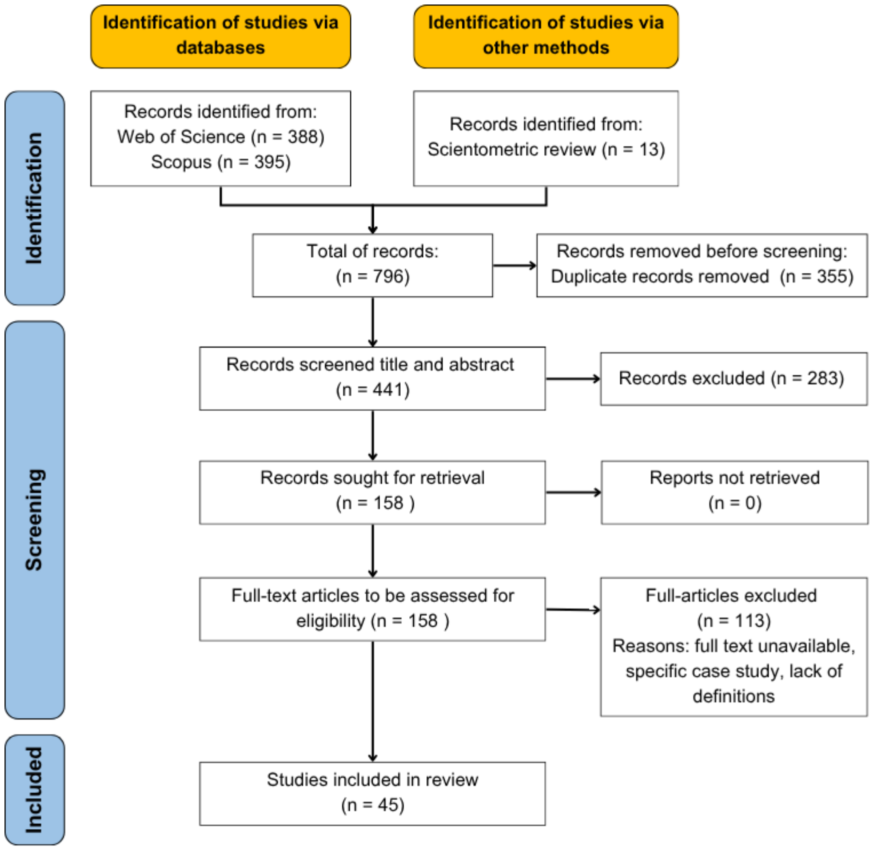

Figure 2. Literature search and selection process using the PRISMA-ScR guidelines.

Table 1. Characteristic of selected articles.

Author (s)	Focus of the Study
AbdelMagid et al. [5]	Transportation resilience for vulnerable populations
Achillopoulou et al. [58]	Roadmap for monitoring-based resilience management/holistic asset management
Adey et al. [4]	Measuring and setting resilience targets for transport infrastructure
Ahmed & Dey [65]	Criticality, vulnerability, and post-disaster road restoration
Amoaning-Yankson & Amekudzi-Kennedy [97]	Expanding transport resilience to sociotechnical approaches
Beitelmal et al. [7]	Climate adaptation strategies for Nigerian transport infrastructure
Bergantino et al. [50]	Review of factors that positively and negatively affect resilience of a transport network
Chan T. [119]	Transport resilience via Multi-Level Perspective (MLP)
Chen H. et al. [13]	Quantifying urban transport resilience using Bayesian Networks (BN)

Table 1. *Cont.*

Author (s)	Focus of the Study
Esmalian et al. [117]	Roadmap for incorporating resilience in transport planning
Gonçalves & Ribeiro [23]	Review of concepts and framework for transport resilience assessment
Gu et al. [92]	Review and comparison of resilience concepts
Islam & Kabir [8]	Systematic review of climate variability impact on transport infrastructure
Ji et al. [115]	Analysis of urban transportation (UT) resilience considering the impact of multiple extreme weather events
Lara et al. [104]	Assessing urban mobility resilience to pandemics
Li S. et al. [120]	Interconnectivity and interdependency of transportation infrastructures
Li Y. et al. [103]	Bibliometric analysis of transportation system resilience
Li Z. et al. [112]	Measurement of flood resilience
Machado-León & Goodchild [101]	Review of performance metrics for community-based resilience planning
Martins et al. [100]	Measuring urban mobility resilience via mode transfer
Mattsson & Jenelius [96]	Discussion on vulnerability vs. resilience of transport systems
Mirzaee & Wang [107]	Analyzing urban mobility resilience using geocoded twitter data
Nickdoost et al. [55]	Prioritizing resilience factors for coastal transport planning
Pan et al. [94]	Review of vulnerability and resilience of transportation system research progress
Reggiani et al. [93]	Critical interpretation of resilience and vulnerability in transportation studies
Roy et al. [24]	Quantify of mobility resilience using geo-located social media data
Serdar et al. [48]	Reviewing methods and indicators for transport resilience assessment
Sohouenou & Neves [118]	Evaluating optimal road network recovery strategies/link repair sequence
Tachaudomdach et al. [113]	Quantifying road network robustness against floods
Tang et al. [21]	Long-term multi-dimensional resilience using Bayesian Network Model
Tori et al. [121]	Developing resilient mobility strategies for future uncertain scenarios
Trotter & Ivory [98]	Identification and engagement of key decision makers to enhance transport network resilience
Twumasi-Boakye & Sobanjo [95]	Review of transportation network resilience concepts, methodologies, and recovery quantification
Wan et al. [99]	Review of transportation resilience definitions, characteristics, and research methods
Wandelt et al. [102]	Estimating and improving transportation network robustness via communities
Wang J. et al. [108]	Measuring functional resilience via robustness, adaptability, and recoverability
Wang N. et al. [105]	Long-term resilience assessment of urban transportation system (UTS) using System Dynamics model
Wang Q. & Taylor [116]	Urban human mobility resilience under multiple natural disasters
Watson & Ahn [111]	Systematic review of transportation infrastructure resilience to flooding events
Wu & Chen [122]	Integration of post-hazard emergency response and pre-hazard mitigation planning to improve transportation system resilience
Xiong et al. [114]	Review of recent resilience studies for road transportation networks under hydrological hazards

Table 1. *Cont.*

Author (s)	Focus of the Study
Zhang L. et al. [109]	Dynamic resilience assessment of multi-modal public transportation (metro disruptions)
Zhang X. et al. [123]	Quantifying road transport resilience during the COVID-19 pandemic
Zhou et al. [106]	Review of transport resilience concepts and methodologies
Zou & Chen [110]	Decision-making framework for the resilience-based recovery scheduling of the transportation network in a mixed traffic environment

Table 2 summarizes the main definitions of resilience in transportation systems found in the selected studies. Notably, most studies refer explicitly to transportation system resilience, from which the concept of urban mobility resilience was derived for the purpose of this research. Resilience in transportation systems is defined as the multifaceted capacity to absorb, adapt to, and recover quickly from disruptive events, restoring the system to a desired functional state—either the original configuration or a new equilibrium [5,23,50,106]. A critical component is the ability to safely meet user demands before, during, and after disasters, and to adapt to changing conditions [5,117].

Many studies adopt the “4 Rs” framework proposed by Bruneau et al. [55,65,92,106,114,124], which categorizes resilience with four main characteristics: robustness, redundancy, resourcefulness and rapidity. Robustness refers to the strength or capacity of a system to resist and withstand the impact of disruptive events without losing its core function or suffering significant degradation [13,23,106,119]. It is often seen as the inverse of vulnerability [92]. Redundancy addresses the availability of alternative resources or components with similar functionality that allow the system to continue operating even in the event of failures, such as optional routes between origins and destinations [13,99,120]. Resourcefulness is related to the ability of the system to identify, prioritize, and mobilize resources—materials and personnel—needed for response and recovery operations [23,65,96,106]. Rapidity refers to the speed and efficiency with which the system can restore its functionality or return to an acceptable operating state after a disruptive event [106,113].

Table 2. Resilience definitions from reviewed documents.

Author (s)	Definition
[5]	“. . .their capability of withstanding disruptions and adapting to changing conditions to safely meet the demands of the users pre-, peri-, and post-disasters”
[4]	“Resilience can be measured as the ability to continue to provide service if a hazard event occurs.”
[97]	“The resilience of the transportation system, defined as the ability of a transportation system to withstand shocks, respond appropriately to threats, and mitigate the consequences of those threats. . .”
[50]	“Transport network resilience is defined as the ability of a transport network to absorb shocks, maintain functionality, adapt to and resist the negative effects of disruptive events, and rapidly recover to a state of equilibrium”
[119]	“Urban transport systems encounter frequent disruptions from both human and natural factors, making resilience—the capacity to with-stand, recover, and adapt—a central focus in their design and operation.”
[23]	“. . .the ability of a system to resist, reduce and absorb the impacts of a disturbance (shock, interruption, or disaster), maintaining an acceptable level of service (static resilience), and restoring the regular and balanced operation within a reasonable period of time and cost (dynamic resilience).”

Table 2. *Cont.*

Author (s)	Definition
[115]	"Urban transportation resilience reflects the ability of the transportation system to maintain its basic functions and structure through its resistance, mitigation, and absorption under extreme conditions (such as public incidents, terrorist attacks, and natural disasters), called static resilience, or the ability to restore the original equilibrium or a new equilibrium state within a reasonable time and cost, called dynamic resilience"
[120]	"The resilience of transportation systems is described as the ability to prepare for and adapt to the disturbances caused by hazards and implement response and recovery strategies to mitigate performance loss."
[112]	". . .this study defines mobility resilience as the capacity of a city to tolerate disturbances and maintain urban mobility to the greatest extent possible through non-linear restructuring, adjustments, transformations, and feedback of traffic flow patterns when road network is damaged by extreme events."
[96]	"The concept of resilience is intended to capture a system's capacity to maintain its function after a major disruption or disaster. It may also include the rapidity with which the system returns to a state of normal operation after such an event."
[107]	". . .the ability of an urban system, its social units (such as individuals, communities, institutions, governments, etc.), and its technical units (urban infrastructure) to recover from hazards while maintaining functional continuity of their substituents and as a whole, and mitigating negative impacts of future hazards through practice of resilience planning."
[55]	"A resilient transportation system should be able to withstand disruptive events and remain functional (i.e., technical aspect), continuously facilitate the movement of people and goods in a safe and efficient manner (i.e., socioeconomic aspect), and have a reduced exposure to natural hazards (i.e., environmental aspect)."
[24]	"We define mobility resilience as the ability of a mobility infrastructure system responsible for the movement of a population to manage shocks and return to a steady state in response to an extreme event."
[98]	"'Resilience' in the context of transport infrastructure has been described in terms of its mobility function: the ability to continue to move people and goods and to ensure a safe, secure and reliable supply chain."
[99]	". . .we refer transportation resilience as the ability of a transportation system to absorb disturbances, maintain its basic structure and function, and recover to a required level of service within an acceptable time and costs after being affected by disruptions."

In addition, the literature highlights other important characteristics: adaptability, vulnerability, preparedness, reliability, and interdependence. Adaptability is the system capacity to adjust, learn, and innovate in response to new challenges or emergencies [23,96,99]. Vulnerability refers to the system's susceptibility to extreme tensions or incidents that can significantly reduce its capacity or service quality [92–94,96]. Preparedness involves the ability to anticipate, prepare for, and implement measures prior to a disruption to reduce its potential impacts [23,96,99]. Reliability is defined as the probability that the transportation network level service remains satisfactory and continues to perform its required functions under specified conditions [13,92,94,103]. Interdependence, or connectivity, refers to the connections and relationships between transportation system components or across different infrastructure systems (e.g., power, communication, and transportation) [48,102,103,120].

Based on the literature synthesis, some characteristics can be reinterpreted or merged. For instance, resourcefulness can be considered as part of preparedness and rapidity, as the system must be adequately prepared, with sufficient resources to manage emergency situations, and must rapidly allocate these resources, identifying critical points to restore a desired functional state. Likewise, interdependence can be integrated into the concept of robustness, considering the internal and cross-system connectivity that strengthens the system's capacity to withstand shocks. Regarding vulnerability and reliability, Gonçalves & Ribeiro [23] concluded that these concepts are interrelated and complementary performance measures to resilience, but not a main characteristic of it. Therefore, in alignment with the definitions of [23,115], this study adopts five core characteristics of resilience in urban mobility—robustness, redundancy, preparedness, rapidity, and adaptability—aligned with the functions of resisting, absorbing, recovering from, and transforming in response to disruptions.

In addition to these characteristics, resilience performance can be structured across five dimensions: economic, natural, institutional/organizational, physical, and social. The economic dimension refers to the system's ability to minimizing direct and indirect economic losses and mobilizing financial resources for recovery [13,96,101,105]. The natural dimension concerns the interaction between the urban mobility system and the natural environment, particularly regarding climate change impacts and system exposure to hazards [105,119]. The institutional/organizational dimension encompasses the governments, institutions, and organizations capacity to manage the system, prepare for, and respond to critical situations [5,13,96,101,113]. The physical dimension focus on the resilience of infrastructure elements, ensuring their functionality under risk conditions [5,105]. Finally, the social dimension addresses the role of users—central components of the system that are directly affected by service disruptions and influence system performance [13,96,97,101,119].

Furthermore, some studies distinguish between two categories of resilience: static resilience and dynamic resilience. Static resilience relates to the system's ability to resist and absorb disruptions while maintaining its core functions. In contrast, dynamic resilience refers to the capacity of the system to recover quickly and adapt or transform during or after disruptive events [13,23,94]. In this context, Nakata-Osaki & Rodrigues da Silva [3] present a comparison, based on a systematic literature review, between case study articles with a static or dynamic scenario type and the number of threats, classified into types. They verified that most of studies address a single threat in a dynamic scenario.

The analysis of the selected studies supported the construction of the framework shown in Figure 3. This framework presents a flowchart of urban mobility resilience, outlining the key characteristics of the system, potential disruptive events, their impacts, and the corresponding system responses. This figure is an adaptation and expansion of the conceptual model originally proposed by Gonçalves & Ribeiro for urban systems [19] and transport systems [23].

We adopt their foundational structure, which organizes resilience into three key phases: before, during, and after a disruptive event. Our original contribution is to populate and specialize this general structure for the specific context of urban mobility, based on our systematic literature review. Specifically, our novel additions to the framework, surrounded by red dashed lines in Figure 3, include:

(1) A detailed characterization of the urban mobility system, specifying its core components and influencing factors.
(2) A typology of disruptive events relevant to mobility (e.g., natural disasters, man-made disasters) and their potential cascading impacts.
(3) The explicit integration of static and dynamic resilience concepts, correlating them with specific system actions like resisting, recovering, absorbing and transforming.
(4) A clear link between system evaluation methods and the proactive actions of mitigation and prevention in the 'before' phase.

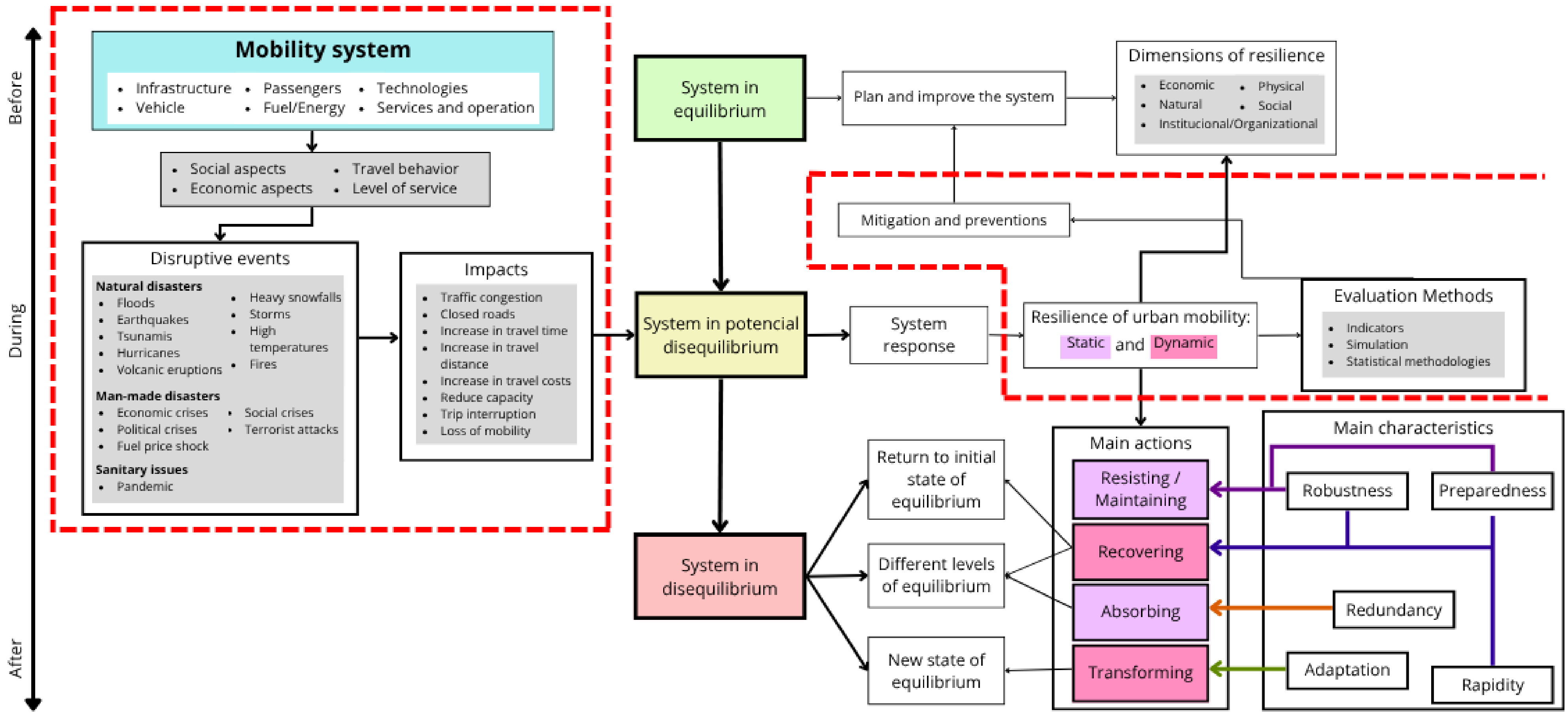

Figure 3. Framework of Urban Mobility Resilience. The flowchart structure is an adaptation of the model proposed by Gonçalves & Ribeiro [19,23]. The new contributions are surrounded by red dashed lines.

3.2. Framework of Sustainable Urban Mobility

Costa [31] defined sustainable urban mobility as a system that fosters economic and social well-being without compromising human health or the environment. It should guarantee basic access and mobility in ways consistent with human health and ecological balance over the long term, while ensuring equity. It is characterized by cost-effectiveness, operational efficiency, and the provision of diverse transportation modes. Additionally, it requires the limitation of emissions and waste, the prioritization of renewable resources, and the reduction in land consumption and noise pollution.

Figure 4 illustrates the hierarchical structure of the I_SUM. The index's construction is predicated on the three pillars of sustainability: social, environmental, and economic. All themes are linked to these pillars [31]. The index applies a multidisciplinary approach to evaluate the performance of sustainable mobility across multiple domains, including accessibility, environmental impact, social implications, political aspects, infrastructure, non-motorized modes of transportation, integrated planning, traffic and urban circulation, and urban transport systems.

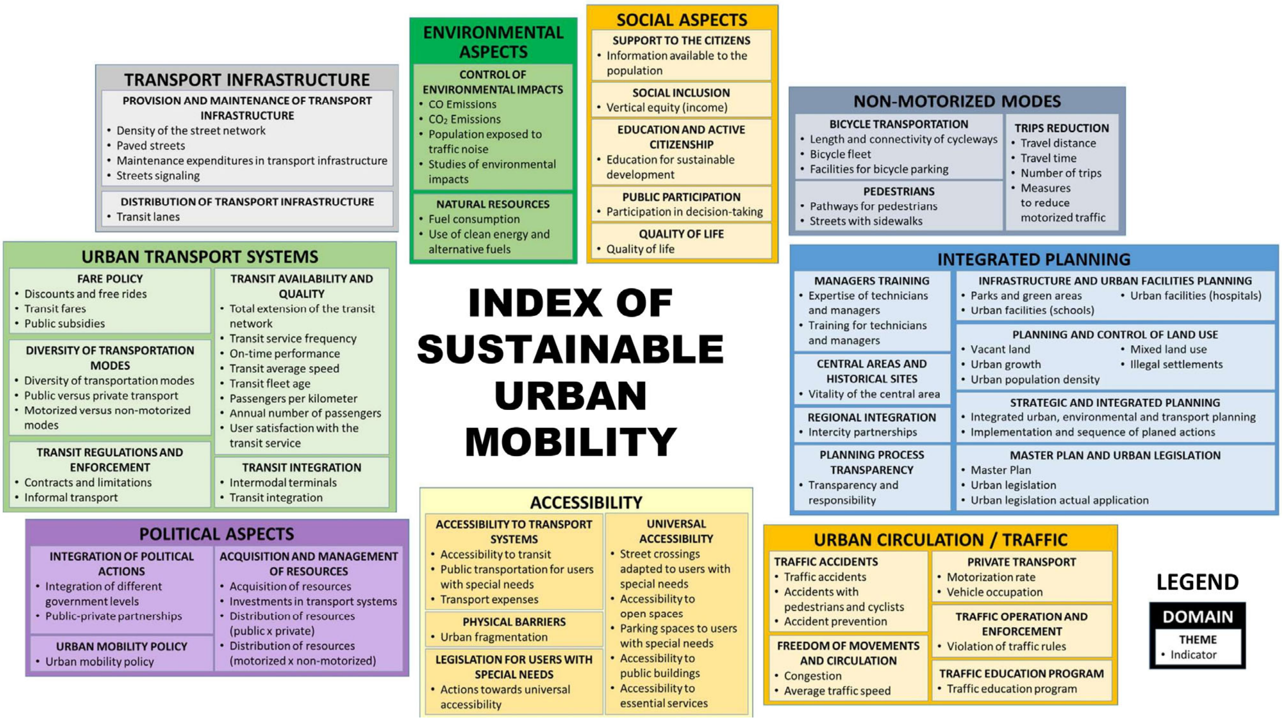

Figure 4. Index of Sustainable Urban Mobility (I_SUM) (Source: adapted from [31]).

Its indicators facilitate the identification of key elements that support decision-making, strategic planning, and urban management by breaking down sustainable urban mobility into various domains and highlighting critical themes, such as quality of life, managerial expertise, and the need for public policies. The index is comprehensive, encompassing social, economic, and environmental dimensions. It is designed to promote a balanced, long-term perspective while encouraging the participation of diverse stakeholders [31].

The domains of accessibility and social impacts carry greater weight in the social dimension of sustainability, while political aspects and infrastructure have greater appeal to the economic dimension. The environmental dimension is primarily represented by the domains of environmental aspects and non-motorized modes. However, it is important to acknowledge that the themes do not address a single dimension in isolation; rather, they are interconnected at various levels, forming an interconnected and dynamic system [31].

Overall, the index covers fundamental principles of sustainable urban mobility, including equity, environmental impacts, public participation in decision-making, infrastructure quality, promotion of multimodal and active transport, integration of political actions, managerial training, and mobility planning aligned with broader urban development strategies.

3.3. Comparative Analysis: Sustainability vs. Resilience in Urban Mobility

To deepen the understanding of how the concepts of sustainability and resilience are applied to urban mobility, a thematic analysis approach was conducted, following the six-step method proposed by Braun & Clark [88]. To illustrate the goal of the work, Figure 5 presents a conceptual diagram that introduces the core components of resilience and sustainability.

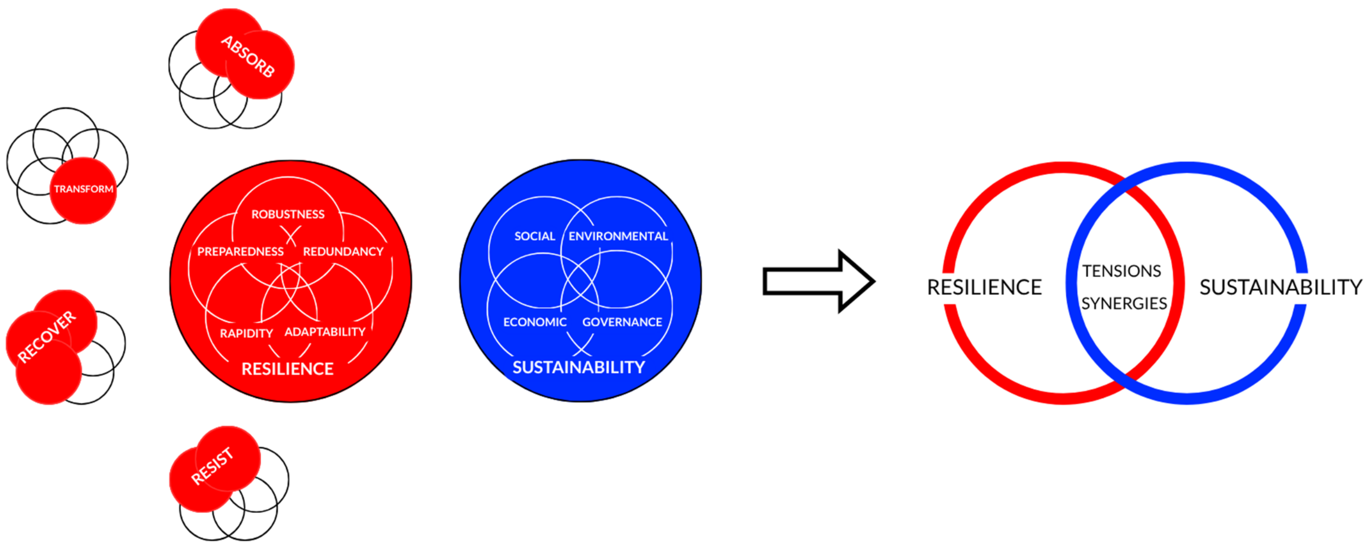

Figure 5. Resilience and sustainability core components. Note: The figure represents resilience (in red) as the combination of robustness, redundancy, adaptation, rapidity, and preparedness. These characteristics are associated with the actions absorb, transform, recover, and resist. Sustainability (in blue) is characterized by the integration of social, environmental, economic, and governmental perspectives. As the figure shows, the objective of the work is to unite these two concepts and their respective characteristics, highlighting their synergies and tensions.

The analysis of resilience was based on the studies previously examined during the development of the analytical framework, from which relevant excerpts were revisited and systematized. For sustainable mobility, the analysis focused on the study by Costa [31] and the Index of Sustainable Urban Mobility, from which key conceptual and operational elements were extracted (Steps 1 and 2). These data were then categorized to identify thematic patterns related to both concepts (Step 3), which were reviewed for coherence and relevance (Step 4) and refined into clearly defined categories (Step 5). As a result, six analytical dimensions were established—definition, objectives, dimensions of analysis, time horizon, guiding question, and key indicators—which form the structure of the comparative Table 3 and serve as the basis for the subsequent discussion (Step 6).

The three dimensions of sustainability are social, economic, and environmental. However, Costa [31] expands these dimensions into nine domains, incorporating governance as a backbone of sustainability. These domains include accessibility, environmental aspects, social aspects, political aspects, transport infrastructure, non-motorized modes, integrated planning, urban circulation and traffic, and urban transport systems. They are connected to all the identified dimensions of resilience in urban mobility. Moreover, themes such as integrated and strategic planning and modal diversification directly relate to the characteristics of preparedness and redundancy, respectively, further reinforcing the analytical dimensions adopted in this comparison. The analysis of resilience indicators for urban mobility reveals a higher concentration of indicators domains of traffic and urban transport systems (public transport), transport infrastructure and environmental aspects [3].

Table 3. Comparative analysis of Sustainable and Resilient Urban Mobility.

Attribute	Sustainable Urban Mobility	Resilient Urban Mobility
Definition	It is a strategy that enables transportation to fulfill its economic and social roles while minimizing its negative environmental impact	It is the system's ability to resist, absorb (static), recover, and transform (dynamic) in the face of a shock
Objectives	To achieve a long-term state that efficiently balances environmental, social and economic results, maximizes well-being, and minimizes damage.	Effectively maintain functionality during and after disruptions, learn and adapt
Dimensions	Social, economic and environmental	Social, economic, natural, physical and institutional
Time horizon	Predominantly long-term, often generational	Immediate (with a focus on the system's response before, during, and after a perturbation) to medium-term (recovery and adaptation planning for future events)
Core question	What is the most desirable, equitable, and efficient system we can create for the long term?	How can we ensure the system continues to function and recovers quickly when faced with unexpected shocks and stresses?
Key indicators	Measures of efficiency, equity and long-term impact (e.g., GHG emissions/capita, modal split, accessibility scores, resource consumption, fatality rates).	Measures of response and recovery (e.g., recovery time, functionality loss, network redundancy, adaptive capacity, performance loss during disruption)

The comparative framework reveals that sustainability is oriented toward long-term systemic transformation, while resilience focuses on the system's ability to absorb and respond to disruptions in the short term. Despite these differences in timescale and immediate objectives, both contribute to improving the functionality and service quality of urban mobility systems and are interconnected in practice. Recognizing these distinctions is essential for developing integrated strategies that combine the strengths of both approaches.

Sustainability actions can influence resilience, resulting in a dynamic relationship that includes synergies and tensions. A comprehensive approach to urban mobility planning must therefore move beyond viewing the concepts in isolation and instead focus on how they interact, identifying and leveraging synergies while acknowledging and managing potential trade-offs.

3.3.1. Synergies Between the Concepts of Sustainability and Resilience in Urban Mobility

Several synergies emerge from the comparison between sustainability and resilience in urban mobility, indicating strong potential for integrated planning strategies. One notable convergence lies in the promotion of multi-modal and active mobility systems. Encouraging walking, cycling, and public transportation not only contributes to sustainability goals (e.g., reducing greenhouse gas emissions, minimizing air pollution, improving public health, and advancing social equity) but also enhances resilience increasing redundancy in the mobility system [23,46,47]. When disruptions affect a primary mode of transport, the availability of viable alternatives ensures continued functionality.

Another strong alignment is the reduction in fossil fuel dependency [100], a shared priority that supports both environmental sustainability and energy resilience. Transport decarbonization—through vehicle electrification and active modes of transport, improved fuel efficiency, and the integration of renewable energy sources—simultaneously mitigates environmental impacts and strengthens energy resilience. Diversifying the energy portfolio used in transport reduces dependence on singular supply chains, thereby improving robustness and lowering vulnerability to global energy shocks and supply disruptions [7].

Green infrastructure functions as a dual-purpose intervention. Features such as green corridors, permeable pavements, and rain gardens contribute to sustainability by enhancing biodiversity, improving air quality, and offering recreational and aesthetic benefits. Simultaneously, they serve resilience goals by managing intense rainfall, mitigating flood risks, and reducing urban heat island effects [7].

Integrated land use and transport planning represents another area of convergence. Approaches such as transit-oriented development (TOD) and compact urban forms reduce the demand for long-distance travel and promote low-carbon mobility, advancing sustainability goals. At the same time, these configurations enhance resilience by allowing residents to access essential services within short distances, thus minimizing dependence on large-scale transport systems in the event of disruption [119,125].

Beyond these practical synergies, both concepts converge around broader societal objectives. Both paradigms recognize the importance of addressing climate change [7,115], ensuring fair access to transport services [5], and promoting inclusive economic development [99]. On the other hand, resilient mobility systems are vital for achieving and maintaining long-term sustainable objectives, by protecting investments against disruptions, and ensuring sustainable behaviors by increasing reliability, safety and accessibility. These shared concerns reinforce the possibility of designing urban mobility systems that are not only sustainable in the long term but also resilient to future uncertainties

To illustrate and analyze the highlighted synergies, Figure 6 presents how specific strategies (e.g., 'Active modes', 'Green infrastructure') impact multiple components of both sustainability (shown in blue) and resilience (shown in red), making co-benefits tangible. In the figure, the colored boxes represent the affected components and the white boxes representing the unaffected components.

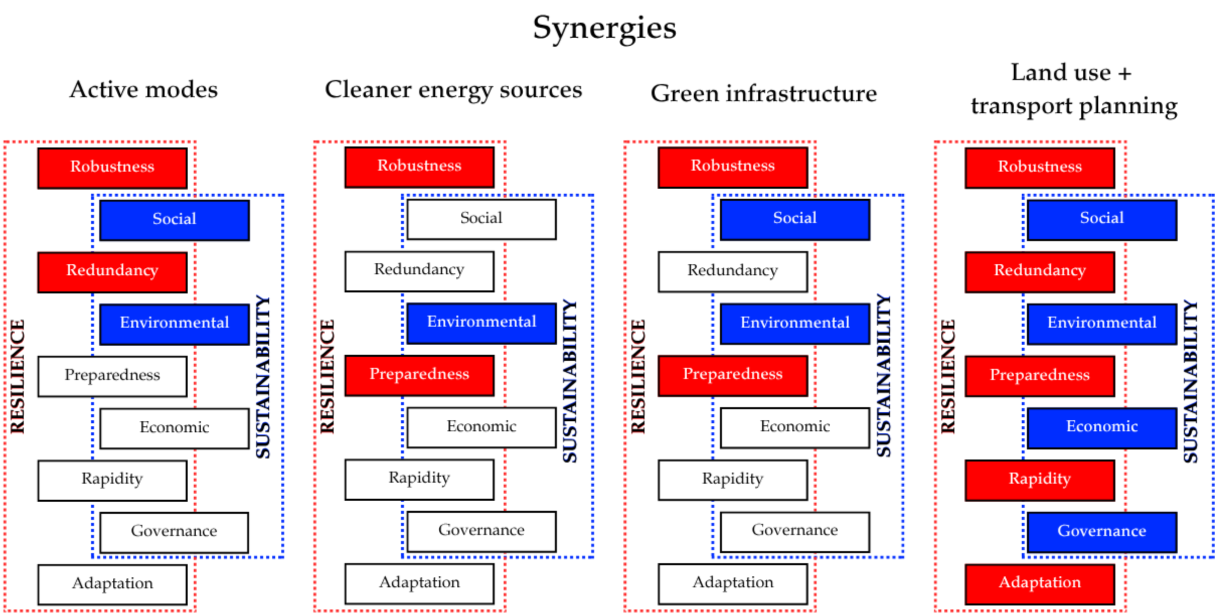

Figure 6. Synergies between the characteristics of resilience and the dimensions of sustainability.

Promoting active modes influences social and environmental sustainability, enhancing resilience robustness and redundancy (the action of absorbing). Promoting cleaner energy sources affects environmental sustainability and increases the system's resilience by impacting its preparedness and robustness, as well as the promotion of green infrastructure. These strategies impact the system's ability to resist disruptive events by reducing fossil fuel consumption and pollutant emissions or creating permeable areas. Integrated land use and transport planning affects all components by impacting urban planning as a whole.

3.3.2. Tensions and Trade-Offs Between the Concepts of Sustainability and Resilience in Urban Mobility

Despite the synergies between sustainable and resilient urban mobility, certain tensions and trade-offs emerge when both objectives are pursued simultaneously. One of the most fundamental contradictions lies in the balance between efficiency and effectiveness [9,126]. The economic pillar of sustainability often promotes efficiency through cost reduction, waste minimization, and non-excessive use of natural resources. In contrast, resilience depends on redundancy—the intentional maintenance of slack in the system, such as duplicate infrastructures and multi-paths, which are often considered inefficient from an economic and environmental point of view.

Another trade-off emerges in the immediate recovery response following extreme events. Post-disaster scenarios often demand fast and low-cost restoration of urban infrastructure, driven by political urgency and societal pressure. This pressure can lead to rapid reconstructions using conventional, carbon-intensive materials and processes, sacrificing long-term sustainability goals for short-term functionality. Alternatively, a more sustainable recovery approach—such as the use of low-carbon materials, circular economy practices like recycling debris, or redesigning infrastructure to incorporate green solutions—may be slower, more complex, and more expensive in the short run. This dynamic reveals a direct conflict between rapidity and sustainability, especially in the face of limited resources and tight timelines [72].

Finally, some sustainable mobility solutions can introduce new vulnerabilities. The growing adoption of electric vehicles, for example, plays a central role in decarbonizing the transport sector. However, the effectiveness of electric vehicles systems depends heavily on the reliability of the electricity grid. Disruptions caused by extreme weather, cyberattacks, technical failures, or energy shortages can compromise the availability of power and, consequently, immobilize large portions of the electric vehicles fleet [48]. This creates a resilience concern, as decarbonization gains may come at the cost of increased exposure to new systemic risks.

Figure 7 provides a detailed visualization of the main tensions. It illustrates how certain objectives and strategies (e.g., 'Rapid recover vs. Sustainability') create trade-offs and potential conflicts between the components of resilience (in red) and sustainability (in blue). In the figure, the colored boxes represent the affected components and the white boxes representing the unaffected components.

To consolidate the comparative findings presented, Table 4 presents an integrative synthesis of the key dimensions of sustainable and resilient urban mobility. This visual representation highlights the conceptual and operational distinctions between the two paradigms, as well as their potential complementarities. It serves as a bridge between the comparative analysis and the subsequent discussion on how to integrate these frameworks into public mobility policies.

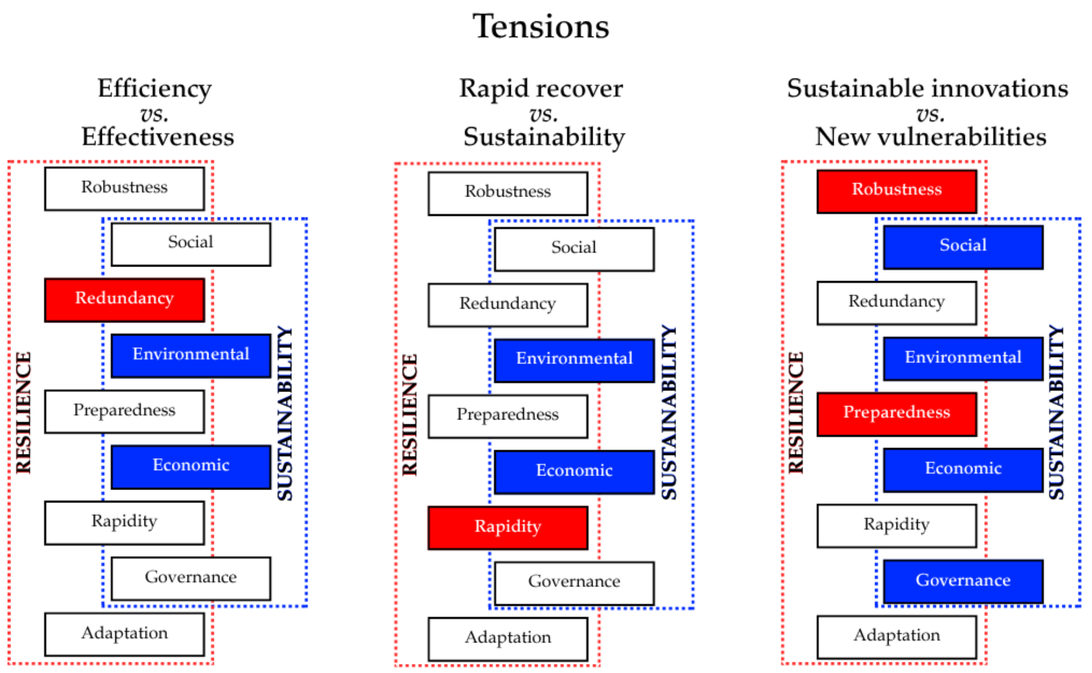

Figure 7. Tensions between the characteristics of resilience and the dimensions of sustainability.

Table 4. Integrated vision of sustainability and resilience.

Attribute	Integrated Vision
Objective	A mobility system that meets users' present needs and guarantees its functionality during disruptive events without compromising the environment or society in the future
Time horizon	Combine long-term planning with emergency preparation and response
Dimensions	Social, economic, environmental, physical and institutional
Indicators	Combine measures of efficiency, equity and long-term impact with measures of response, recover and adaptation

4. Discussion

The coexistence of strong synergies and inherent trade-offs between sustainability and resilience highlights the complexity of incorporating these concepts into urban mobility planning. As Nakata-Osaki and Rodrigues da Silva [3] emphasize, it is imperative to comprehend the reciprocal impact of these factors on transport systems. While there is a relationship between sustainable urban mobility and resilient mobility, it is important to note that sustainable urban mobility is not automatically resilient, and resilient mobility is not necessarily sustainable. In the context of urban mobility, these concepts are understood as distinct objectives that can be pursued in conjunction.

Although both paradigms enhance system performance, their conflicting priorities necessitate careful negotiation. These findings raise important questions about how to operationalize a balanced approach, especially in the design and implementation of long-term public policies. Esmalian et al. [117] identify several challenges in incorporating transport planning and project development. These include institutional obstacles, as financial constraints, lack of formal programs and guidelines, and limited cross-sectoral coordination and integration; technical barriers, as insufficient personnel with expertise, inadequate training, and lack of tools and methods; and informational gaps, as limited or unreliable data and insufficient performance metrics. These systemic shortcomings constrain the ability of cities to plan, execute, and monitor integrated interventions aligned with long-term goals.

Addressing these barriers is critical to developing a resilient and sustainable urban mobility system. These challenges are not isolated; they reflect deep-rooted institutional, technical, and operational limitations [117] that reduce the capacity of cities to anticipate, absorb, and adapt to disruptions while advancing low-carbon, inclusive mobility goals.

First, informational gaps, particularly the lack of reliable data and integrated performance indicators, obstruct evidence-based decision-making [5,48]. Without consistent metrics that address both sustainability and resilience, it becomes difficult to assess trade-offs, identify synergies, and evaluate the long-term impacts of interventions [29]. Filling this gap requires developing comprehensive indicator systems that incorporate and monitor sustainability and resilience dimensions.

Second, institutional weaknesses, such as the absence of formal frameworks, fragmented responsibilities, and short-term planning horizons, undermine continuity and coordination. Resilient and sustainable mobility requires continuity, coordination, and policy alignment across sectors, levels of government and stakeholders [31,117]. Incorporating these objectives into urban mobility plans and integrating them with broader climate and development strategies ensures consistency and accountability.

Third, limited technical capacity is a significant barrier. A shortage of qualified personnel, limited training opportunities, and inadequate access to planning tools hinder the ability of local governments to design and implement effective solutions [31,117]. Overcoming these constraints requires sustained investments in capacity building, interdisciplinary education, and tools that support planning under uncertainty.

In addition, it is important to actively involve the community in mobility planning [31]. Building inclusive and equitable mobility systems depends not only on technical solutions but also on public participation that reflects diverse user needs and preferences. Engaging communities fosters a sense of ownership, enhances the legitimacy of decisions, and builds a culture of shared responsibility; key to enhancing both resilience and sustainability.

Finally, integrating resilience and sustainability into public mobility policies requires a shift toward systems thinking. Urban mobility must be understood as an interconnected element of the broader urban ecosystem—linked to land use, energy, environmental quality, and social equity—rather than as an isolated set of transport services [9]. Recognizing these interdependencies allows decision-makers to design interventions that generate co-benefits across sectors and scales, strengthening both the adaptive and transformative capacities of urban systems.

This analysis emphasizes that building resilient and sustainable urban mobility requires more than technical solutions, it demands a holistic and integrated policy approach. The following conclusions summarize the main insights and highlight their implications for planning and decision-making.

5. Conclusions

This study developed an analytical framework to compare the concepts of sustainability and resilience in urban mobility, based on a scoping review and thematic analysis. The findings underscore the importance of a holistic approach that integrates sustainability and resilience as complementary dimensions in the development, planning and management of long-term urban mobility systems, capable of meeting societal needs for access and movement while protecting the environment and withstanding disruptions.

The primary contribution of this study is the formulation of a structured analytical framework that integrates urban mobility, sustainability and resilience. This framework addresses five key research gaps identified at the intersection of these areas. From the thematic analysis of sustainability and resilience, three main conclusions emerge:

(1) The pursuit of sustainability and resilience in isolation is insufficient and can be counterproductive—the existence of trade-offs between the two concepts demonstrates that pursuing one in isolation may compromise long-term system performance. Tensions such as efficiency versus redundancy, rapid recovery versus sustainability, and innovation versus new vulnerabilities show that aligning these agendas is not automatic and requires strategic and evidence-based decision-making.
(2) Significant synergies exist and offer pathways for integrated "win-win" solutions—despite their differences, the concepts converge in several strategic areas, including responses to climate change and the promotion of equal access to mobility. Priorities such as diversifying transport modes, developing green infrastructure, promoting renewable energy sources, encouraging active mobility, and integrating planning highlight the potential for designing systems that are both sustainable and resilient.
(3) A holistic approach requires navigating trade-offs, not just seeking synergies—advancing toward an integrated sustainable and resilient system demands a multi-level strategy, moving beyond isolated interventions toward a systems-oriented perspective.

In summary, the present research demonstrates that integrating sustainability and resilience is not merely an option, but a necessity for developing enduring urban mobility systems.

6. Practical Recommendations

The proposed perspective views urban mobility as part of a broader urban ecosystem, intricately linked to land use, environmental quality, social equity, and governance. Adopting this holistic vision allows policymakers to design interventions that generate co-benefits across sectors and scales, strengthening cities' ability to absorb shocks while promoting inclusive and sustainable urban development. Achieving this vision requires coordinating policies across levels of government, strengthening public participation, and investing in technical training and planning tools.

Based on our findings, we propose the following actionable steps:

(1) Problem identification—First, managers must identify the city's mobility challenges in order to target their actions effectively. This should be done through public consultations and meetings, as well as technical evaluations. Early stakeholder engagement ensures that both transport-specific challenges and community needs are integrated into the planning process.
(2) System diagnosis—After identifying the problems, the next step is to analyze the system's current situation. Because urban mobility is part of the city's ecosystem, collaboration among all levels of government and stakeholders is essential. A resilient and sustainable mobility diagnosis requires both quantitative and qualitative data collection, including travel surveys, accessibility indicators, exposure to climate-related risks, and current state of infrastructure. Framing the diagnosis within both sustainability and resilience allows planners to identify trade-offs and synergies efficiently.
(3) Definition of objectives and priorities—Objectives should reflect the integration of sustainability and resilience. Because resources are limited, prioritization should favor measures that deliver co-benefits across both paradigms. The focus should be on addressing critical problems for the majority of the population and ensuring equitable access to mobility.
(4) Design of actions—The proposed actions should consider the developed framework, seeking solutions that increase resilience and sustainability while navigating synergies and trade-offs. Planners should prioritize investments in measures that have clear synergistic effects, such as redundancy in critical routes and active mobility infrastructure.

(5) Implementation and monitoring—Planning does not end at project delivery. Actions must be monitored using integrated indicators. Continuous monitoring allows practitioners to adapt strategies over time, ensuring that mobility systems remain both sustainable in the long term and resilient to short-term shocks.

Besides supporting new projects, the framework can also be applied to evaluate existing mobility plans, highlighting tensions and synergies in proposed solutions and guiding adjustments to ensure alignment with both sustainability and resilience goals.

7. Future Research Directions and Limitations

To support the transition to a sustainable and resilient urban mobility, future research should focus on developing integrated indicators that capture both paradigms within a single analytical framework. This involves combining metrics that reflect environmental performance (e.g., as greenhouse gas emissions, modal share, and air quality) with metrics that assess system robustness, redundancy, and recovery capacity. Specific examples include composite indicators linking land use and travel time, or integrating system redundancy with quality of public transportation and infrastructure availability for active modes.

Methodologically, this could be pursued through multi-criteria evaluation models, weighted indicator systems, or resilience-sustainability indexes adapted for urban mobility. These integrated metrics would support evidence-based decision-making by enabling planners and experts to identify co-benefits, anticipate trade-offs, monitor the progress of implemented measures, and prioritize actions that enhance long-term sustainability and short-term resilience simultaneously.

Another critical next step is the empirical application and validation of the proposed analytical framework through a case study. Analyzing a specific city or region would test the operational value of the framework in a real-world context, helping refine its components and revealing context-specific synergies and tensions. Such an application would be invaluable for translating this conceptual work into actionable guidance for urban planners and policymakers, strengthening the argument for an integrated approach.

Finally, this study has some limitations that should be noted. The development of the resilient urban mobility framework was restricted to scientific articles published in English and indexed in two databases (Scopus and Web of Science). While this focus ensured a baseline of academic rigor, it inevitably introduced potential publication and language biases, as relevant studies from other databases or in other languages may have been omitted. Furthermore, the explicit exclusion of gray literature, such as theses, practice-oriented reports, and policy documents, may have limited the framework's inclusion of valuable insights from real-world planning and implementation contexts. Lastly, the specific search criteria described in the Materials and Methods may have unintentionally excluded other relevant studies. Future research could build on this work by addressing these limitations, for instance, by expanding the search to include additional databases, languages, gray literature sources and by including additional mobility indices.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land14102063/s1. Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist.

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