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Review of indicators and multi-criteria decision-making methods for assessing the sustainability of urban mobility

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Assessing the sustainability of urban mobility requires clear indicators and robust decision-making tools, yet current knowledge remains fragmented and unevenly distributed across regions. This study conducts a structured literature review of 38 recent publications to identify the main indicators and multi-criteria decision-making (MCDM) methods used to evaluate sustainable urban mobility. Thirty-five representative indicators were identified, covering traditional sustainability dimensions (economic, environmental, and social) as well as emerging ones such as operational-technical and spatial-urban. Among the MCDM methods, the Analytic Hierarchy Process (AHP) is the most frequently applied for weighting indicators, while the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is commonly used for prioritizing alternatives. The review also highlights key research challenges, including the need for indicator sets adapted to local contexts, the generation of more region-specific information for Latin America, and the development of approaches that account for data availability and local conditions. To address these gaps, a structured expert consultation was conducted in the medium-sized Latin American city of Bahía Blanca (Argentina), resulting in a set of twelve indicators considered suitable for assessing the sustainability of the local urban mobility system. Overall, the study provides an updated overview of current practices and methodological trends in sustainable urban mobility assessment.

KEYWORDS
composite index, indicators, MCDM methods, smart cities, sustainability, TOD, urban mobility

1 Introduction

Sustainable urban mobility can be defined as mobility that meets people's travel needs without harming the environment, human health, or the economy, which is in line with the Sustainable Development Goals (SDG) set by the United Nations in 2015 (United Nations, 2015; Gudmundsson et al., 2016). In this sense, and considering that cities have grown rapidly in recent decades, one of the greatest challenges facing today's cities is to achieve smarter and more sustainable mobility (Mavlutova et al., 2023; Miskolczi et al., 2021; Ruiz Bargueño et al., 2021). It is known that currently 50% of the world's population lives in cities. Furthermore, it is expected that by 2050 this figure will grow to ~70%, making it necessary to solve current mobility problems as soon as possible to prevent them from worsening over time (World Bank, 2023; Demir et al., 2022; Senne et al., 2021; United Nations, 2018).

Urban mobility consists of all journeys made by citizens using the different means of transport available (da Silva et al., 2022; Zapolskytė et al., 2022). That is why, when planning or redesigning a city's mobility, it is necessary to assess the proportion of motorized and non-motorized modes of transport that will create a balance in urban sustainability (Gulcimen et al., 2023). In this regard, walking and cycling can be considered the main non-motorized modes of transport, as they are cheaper, environmentally friendly, and most commonly used for short trips (Abduljabbar et al., 2021). Accordingly, it should be noted that electric micro-mobility (scooters, motorcycles, and bicycles) is also used for short distances (Grassi and Díaz, 2023). On the other hand, for longer distances, public passenger transport, such as buses, is a necessary motorized means for efficient and comfortable urban transport, which reduces the use of private vehicles (Gulcimen et al., 2023; Senne et al., 2021). Likewise, the incorporation of shared mobility alternatives should be taken into account (Morfoulaki and Papathanasiou, 2021; D'Orso et al., 2020). It is well known that sustainable, efficient, and well-designed transportation systems improve the quality of life of citizens, as they are a vital social resource that enables community life, providing access to education, health, work, recreation, and social interaction (Mavlutova et al., 2023; Costa et al., 2017). As Sultana et al. (2017) and Hoornweg et al. (2011) correctly point out, the cities have the capacity to implement comprehensive public policies that could mitigate the negative effects of urban mobility and thus promote more sustainable mobility over time. This is achieved thanks to detailed knowledge of local customs and their smaller size compared to a province or country.

In sustainability assessments of urban mobility, indicators and composite indices are widely recognized as essential tools to organize and systematize complex information, enabling comparability across contexts and supporting evidence-based decision-making (Medina et al., 2020; Senne et al., 2021; Ramani, 2018; Danielis et al., 2017; Gudmundsson et al., 2016). These tools are essential, as they allow for the evaluation of a large volume of information in a simple and clear manner (Gulcimen et al., 2023). In addition, they provide statistics that serve as a database for evaluating trends over time, as well as quantifying the impact of new measures taken or interventions carried out on urban mobility (Medina et al., 2020; Tripathy et al., 2019; Ramani, 2018; Kolak and Feyzioglu, 2016; Castillo and Pitfield, 2010). However, there is no single set of indicators that is associated with the need to adapt the indicators to the different urban contexts studied, i.e., the particularities of each city's structure must be considered, as well as the objectives to be achieved and the availability of data and information (Medina et al., 2020; Jain and Tiwari, 2017). For sustainable urban mobility management, it is necessary to have a general decision-making process that takes into account the needs of each of the stakeholders involved, with the aim of choosing the best possible alternative (Gulcimen et al., 2023; Oses et al., 2017). It should be noted that decision-making is not an easy or simple process, especially when there are conflicting objectives. In this sense, multi-criteria decision-making (MCDM) methods are a branch of operational research that assist in decision-making when there are various criteria that, in most cases, are in conflict (da Silva et al., 2022; Hajduk, 2021; Rivero Gutiérrez et al., 2021; Oses et al., 2017). In other words, some MCDM methods have a significant impact when it comes to choosing the best alternative. These methodologies allow multiple conflicting criteria to be formally incorporated into the management planning process (Ruiz Bargueño et al., 2021). These methods are essential for decision-makers, as they help them manage and weigh the various points of view of all stakeholders involved and find compromise solutions to decision problems involving tangible and intangible criteria that are contradictory (Thakkar, 2021; Saaty and Ergu, 2015). Although there are many MCDM methods, the Analytic Hierarchy Process (AHP), proposed by Saaty (1977), is one of the most widely used in various decision-making applications (Guggeri et al., 2023; Darko et al., 2019; Russo and Camanho, 2015; Vaidya and Kumar, 2006). This predominance is also evident in the field of sustainable urban mobility, where AHP has been frequently applied to prioritize indicators and evaluate alternative measures. Its popularity stems from the ability to structure complex problems into hierarchies and to facilitate pairwise comparisons of criteria, while offering an interpretation that is accessible to stakeholders (da Silva et al., 2022; Zapolskytė et al., 2022; Ištoka Otković et al., 2021; Gompf et al., 2021; Senne et al., 2021; D'Orso et al., 2020; Yannis et al., 2020; Castillo and Pitfield, 2010; Campos et al., 2009; Costa et al., 2005). In this context, although numerous indicators and MCDM methods have been applied, and international initiatives such as the European Union's Sustainable Urban Mobility Indicators (SUMI) are available, important challenges remain in assessing sustainable urban mobility. However, the scientific literature still does not provide clear guidance on which approaches or methods are most suitable for specific urban contexts. Even less is known about which indicators are best suited to specific scenarios and how they should be applied. This gap underscores the main objective of this review, which is to analyze, identify, and organize academic contributions in order to identify the main approaches used in assessing the sustainability of urban mobility.

Building on this, the present study offers a systematic overview of sustainability assessment in urban mobility, with a special focus on indicators and MCDM methods, to identify research needs and recommendations. The study structures and analyzes the available literature, conducting a review study on the use of indicators and MCDM methods in the study of urban mobility sustainability. The methodology used to conduct the structured literature review and bibliometric analysis is presented, followed by the classification of the indicators and MCDM methods. The results are then discussed, and the main research challenges encountered are outlined. While the study of urban mobility has gained importance worldwide, it remains scarce in Latin American countries, where the dynamics of transportation systems face specific challenges (Velasco Arevalo and Gerike, 2023; da Silva et al., 2022). These include pronounced socioeconomic inequalities that limit access to formal transport, the prevalence of informal and unregulated modes, insufficient investment in public and non-motorized infrastructure, and urban sprawl that increases travel distances and car dependency (Aprigliano et al., 2023; Ferrari et al., 2021; Morea, 2021; Vasconcellos, 2015). Additional problems, such as congestion, air pollution, and traffic accidents, further hinder the development of sustainable mobility in the region. These characteristics highlight the need for context-sensitive frameworks that can address the unique realities of Latin American cities.

For this reason, it is essential to generate approaches and tools that allow for the analysis of the level of sustainability of mobility in cities with different characteristics and resources (da Silva et al., 2022). With such knowledge, it becomes possible to collaborate with decision-makers in the transformation of public space, focusing on people, improving the quality of life, and prioritizing active mobility and public passenger transport. As mentioned by Zunino Singh et al. (2020), it is time to rethink urban mobility, the use of public space, and city planning, seeking to generate public policies in favor of achieving sustainability in transportation and urban development models. In this context, the present work proposes a framework in which relevant indicators are identified to assess the sustainability of urban mobility in medium-sized Latin American cities with growth potential.

2 Problem relevance

2.1 Urban mobility

Urban mobility can be defined as the set of journeys made by people and goods within an urban environment, using various means of transport. Likewise, urban mobility must guarantee the vital movement of people, goods, and services (Zapolskytė et al., 2022). However, today we consider urban mobility to be not only physical movement, but also the integration of people, products, information, and activities (da Silva et al., 2022). This concept encompasses not only vehicular traffic, but also pedestrian travel, bicycle use, micro-mobility, and new emerging forms such as shared or autonomous vehicles, all of which are related to the concept of the smart city (da Silva et al., 2022; Hajduk, 2021; Ištoka Otković et al., 2021). In this sense, urban mobility is not limited to how we move, but reflects how we inhabit and experience the city. Over time, means of transport have evolved in response to technological, cultural, environmental, and social changes. Thus, urban mobility is constantly being redefined, incorporating not only technical innovations but also new citizen demands and criteria of equity, accessibility, and quality of life (Felix et al., 2019; Ramani, 2018). It is well known that the way we move conditions our opportunities, connections, and lifetimes (Almashhour et al., 2023; Demir et al., 2022). On the other hand, the use of public space has taken on increasing prominence in urban planning agendas. It is no longer conceived solely as a physical support for vehicular traffic, but as a multifunctional setting that should promote meeting, recreation, biodiversity, and climate resilience, as well as offer conditions for active and safe mobility (Hajduk, 2021; Morfoulaki and Papathanasiou, 2021; Senne et al., 2021; Ištoka Otković et al., 2021; Campos et al., 2009). Moreover, it is important to note that decisions regarding urban mobility have environmental, economic, and social effects, among others (Almashhour et al., 2023; Gulcimen et al., 2023). From reducing emissions and energy consumption to improving territorial equity and public health, mobility is a strategic axis for sustainable development. Therefore, thinking about urban mobility today implies adopting a systemic, interdisciplinary approach focused on collective wellbeing (Senne et al., 2021; Basbas and Papanikolaou, 2009).

2.2 Sustainability

There is a growing consensus among specialists, planners, and international organizations that both urban designs and transport systems should be oriented towards sustainability (Demir et al., 2022; Medina et al., 2020; Ghodmare et al., 2019; Tripathy et al., 2019; Oses et al., 2018; Maciel and Freitas, 2015; Basbas and Papanikolaou, 2009). This means not limiting ourselves to environmental aspects alone, but also incorporating economic, social, and emerging dimensions, in line with the Sustainable Development Goals (Ramani, 2018). Within this framework, there is an urgent need to "be" sustainable or, at least, to move decisively towards that horizon. However, achieving this is a complex challenge. On the one hand, urban life and mobility systems have become increasingly diverse, dynamic, and fragmented, while on the other hand, the very definition of sustainability has evolved (Kolak and Feyzioglu, 2016; Basbas and Papanikolaou, 2009). Given this complexity, it is essential to have conceptual, methodological, and operational tools to guide the design, planning, and decision-making processes related to urban mobility. These tools must allow for the alignment of efforts, resources, and criteria so that urban interventions effectively contribute to improving sustainability in its many dimensions. Designing with sustainable criteria, therefore involves thinking about transport systems that connect without excluding, that reduce emissions without increasing inequalities, and that integrate public space as a common good (Zapolskytė et al., 2022; Mahmoudi et al., 2019; Maciel and Freitas, 2015). In this sense, urban mobility becomes a strategic axis for transforming cities into more resilient, equitable, and livable environments.

2.3 Indicators

Indicators are fundamental tools for analyzing, measuring, and interpreting the extent to which an urban action, design, or system effectively contributes to sustainable mobility (Gudmundsson et al., 2016). Their main function is to translate complex concepts into explicit metrics, whether qualitative or quantitative, that allow for the evaluation of scenarios, comparison of alternatives, and guidance of decisions (Senne et al., 2021). These indicators provide a scale of comparison that makes it possible to establish when one proposal is "more" sustainable than another, or when it contributes more significantly to sustainability objectives (Medina et al., 2020; Tripathy et al., 2019; Ramani, 2018; Kolak and Feyzioglu, 2016; Castillo and Pitfield, 2010). In this sense, indicators not only allow for measurement but also for the communication and formalization of concepts of sustainability in a way that can be understood, shared, and used by different urban agents: planners, policy makers, technicians, organized citizens, among others (Costa et al., 2005). Furthermore, indicators allow for the standardization of interpretations of complex urban realities, facilitating the generation of comparative studies, comprehensive diagnoses, and strategies for continuous improvement (Gulcimen et al., 2023; Castillo and Pitfield, 2010). This is particularly relevant given that sustainability is now recognized as a multidimensional issue. Therefore, having adequate indicators, or generating new indicators that capture this complexity, is key to guiding design, planning, and decision-making processes. These tools make it possible to align efforts, optimize resources, and provide efficient solutions based on methodologies and techniques appropriate to each context.

It is worth noting that the literature review conducted in this study identified over 400 indicators used to measure the sustainability of urban mobility in published scientific papers. This represents a very broad universe that requires careful attention, particularly in selecting the most relevant indicators that can be adapted to the local realities of different cities, taking into account their specific characteristics such as size, cultural context, habits, and economic function, among others. Furthermore, two main approaches can be distinguished among the studies analyzed: one aimed at comprehensively evaluating a city's urban mobility systems, and the other focused on evaluating the effectiveness of Transit-Oriented Development (TOD) strategies applied in specific areas of a city. Both approaches seek to promote sustainable urban development, though with subtle differences. The first evaluates urban mobility systems holistically, considering economic, environmental, social, and emerging dimensions, while TOD indicators emphasize land use, the integration of residential, commercial, and recreational spaces, and proximity to public transport. In summary, sustainability indicators provide a global vision of the effectiveness of urban transport systems in achieving sustainability goals, whereas TOD indicators focus on the specific urban development features that facilitate public transport use and reduce automobile dependency in a given area of the city. For this reason, in the section analyzing the indicators identified in the literature, both approaches will be presented separately.

2.4 MCDM

MCDM methods are a set of analytical tools designed to address decision-making problems involving multiple criteria, which are often conflicting (Almashhour et al., 2023; da Silva et al., 2022; Hajduk, 2021; Rivero Gutiérrez et al., 2021; Oses et al., 2017). In these scenarios, improving performance in one objective may involve sacrificing performance in another, which prevents the application of a single or linear optimization logic. These types of problems are characteristic of environments with multiple stakeholders who have diverse and, in many cases, conflicting interests. Furthermore, in these contexts, no actor has a dominant hierarchy that allows them to unilaterally impose their conditions, so methodologies are required that allow for the construction of acceptable and balanced solutions for all involved (Ruiz Bargueño et al., 2021). The same occurs when the indicators to be considered have similar relative importance, which prevents one from being clearly prioritized over another. In these cases, MCDM methods allow the problem to be structured, indicators to be weighted, alternatives to be compared, and solutions to be obtained that balance the different objectives at stake (Maciel and Freitas, 2015). Sustainable urban mobility represents a paradigmatic case of this type of problem. It brings together multiple dimensions (environmental, social, economic, technical, among others) and multiple actors (citizens, governments, companies, organizations) who may have divergent perspectives on what it means to "be sustainable" and on which dimension should be prioritized in each context. In this context, MCDM methods provide the rationality needed to address this complexity, allowing scenarios to be analyzed, alternatives to be evaluated, and efficient and justified solutions to be constructed (Thakkar, 2021; Saaty and Ergu, 2015). However, for these methods to be truly effective, it is essential to have appropriate indicators that can clearly estimate the impact of different decisions and be relevant to the local context and to the nature of the problem.

2.5 Research contribution

This work is part of a field of study with a vast academic output, where valuable approaches to urban mobility, sustainability, indicators, and MCDM methods abound. However, despite the volume and richness of the literature, there are still gaps that limit the effective articulation between these concepts in real planning and decision-making contexts. The main contribution of this research lies in offering a systematization of sustainability indicators applicable to urban mobility, linking them explicitly to the different dimensions that comprise it: environmental, social, economic, and emerging. This organization makes it possible to overcome conceptual dispersion and move towards a more structured, operational, and communicable reading of the problem. The work also characterizes the dimensions of sustainability in terms of their relative weight within urban mobility problems, recognizing that these do not have a fixed hierarchy, but rather that their relevance varies according to the context, the actors involved, and the objectives of the analysis. This characterization allows for the construction of models that are more representative and sensitive to urban reality, and opens up the possibility of applying decision-making methodologies that take this variability into account. Likewise, this paper provides a critical analysis of the MCDM methods used in the literature to address sustainable urban mobility issues, identifying the context in which they were used and their applicability to the various issues raised in the literature. This review allows us to guide methodological choices and improve efficiency in complex decision-making, especially in contexts where interests are conflicting and the dimensions of analysis have similar relative importance, as is the case in urban mobility. Overall, the work provides an integrated conceptual and methodological basis that allows complex sustainable urban mobility problems to be addressed with greater precision, transparency, and capacity for coordination between actors. The proposal seeks to align MCDM indicators and methods, generating useful tools for researchers, planners, and public decision-makers committed to sustainable urban development. As such, our work concludes by proposing a set of indicators, evaluated by a panel of experts, to analyze the sustainability of urban mobility in medium-sized Latin American cities.

3 Data collection and analysis

The present literature review includes scientific articles published in Scopus up to the date of the general search (28 November 2024). Scopus was selected as the sole database

TABLE 1 Keywords used for the literature search.

	AND	Analysis	***AND***	Urban mobility	***AND***		***AND***	Index
		OR		***OR***				***OR***
		Decision-making		Transport				Indicators
Multi-criteria		***OR***		***OR***		Sustainable		***OR***
OR		Decision aid		Mobility		***OR***		Indicator
Multicriteria		***OR***		***OR***		Sustainability		***OR***
		Decision making		Transportation				Evaluation criteria
		OR		***OR***				***OR***
		Selection		Traffic planning				Assessment criteria

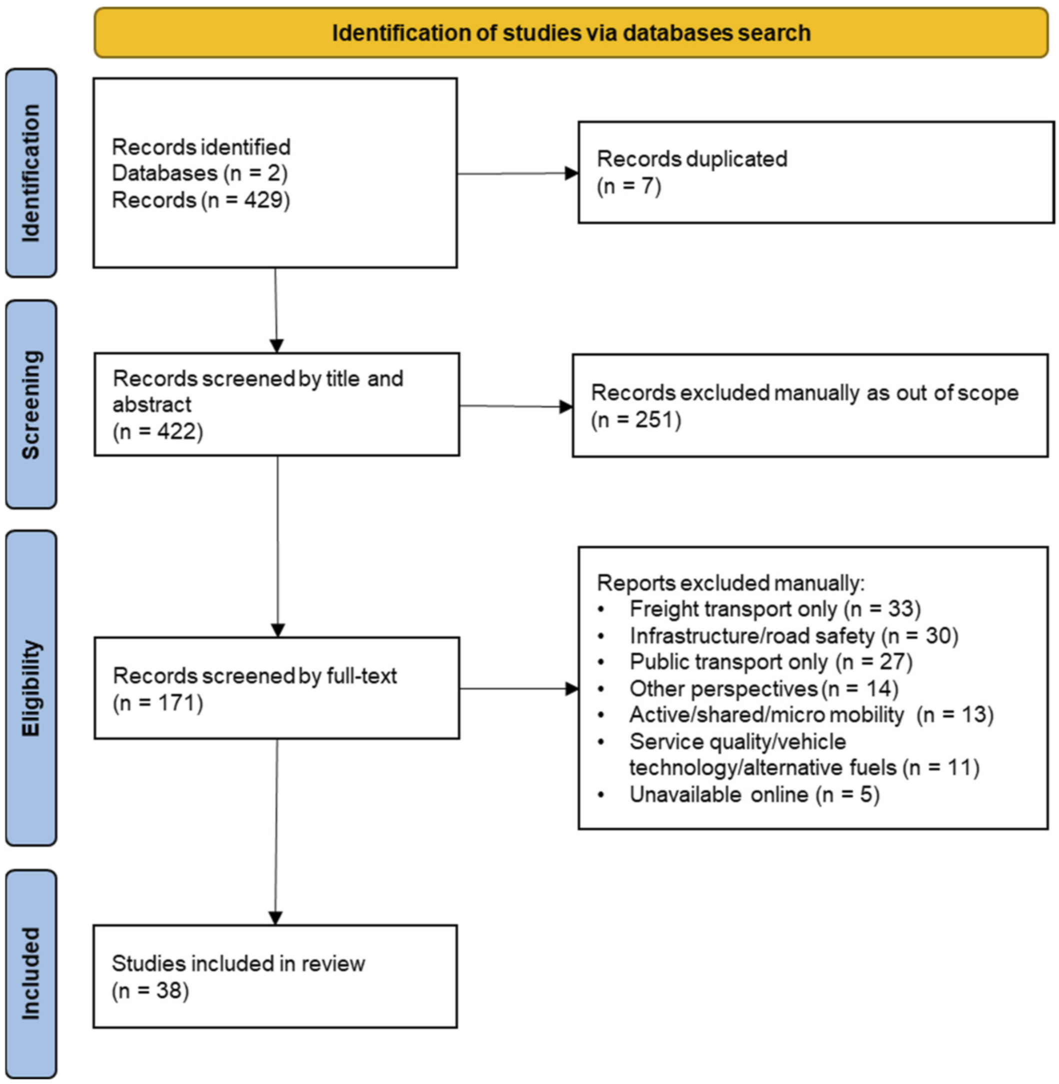

FIGURE 1
PRISMA flow diagram for the article selection process of the present study.

TABLE 2 Key data from the 38 documents selected for more rigorous analysis (citation, title, and journal).

Citation	Title	Journal
Abdullah et al. (2024)	Managing transit-oriented development: A comparative analysis of expert groups and multi-criteria decision making methods	Sustainable Cities and Society
Anwar et al. (2024)	Measuring the Transit-Oriented Development (TOD) levels of Pakistani megacities for TOD application: A case study of Lahore	Sustainability
Almashhour et al. (2023)	Highway transportation, health, and social equity: A Delphi-ANP approach to sustainable transport planning	Sustainability
Gulcimen et al. (2023)	Robust multicriteria sustainability assessment in urban transportation	Journal of Urban Planning and Development
Ibrahim et al. (2023)	Measuring Transit-Oriented Development (TOD) levels: Prioritize potential areas for TOD in Alexandria, Egypt using GIS-Spatial Multi-Criteria based model	Alexandria Engineering Journal
Uddin et al. (2023)	Revolutionizing TOD planning in a developing country: An objective-weighted framework for measuring nodal TOD index	Journal of Advanced Transportation
Siksnelyte-Butkiene and Streimikiene (2022)	Sustainable development of road transport in the EU: Multi-criteria analysis of countries' achievements	Energies
da Silva et al. (2022)	A multi-criteria approach for urban mobility project selection in medium-sized cities	Sustainable Cities and Society
Nodari et al. (2022)	From traditional to electrified urban road networks: The integration of fuzzy Analytic Hierarchy Process and GIS as a tool to define a feasibility Index—An Italian case study	World Electric Vehicle Journal
Demir et al. (2022)	Toward sustainable urban mobility by using Fuzzy-FUCOM and Fuzzy-CoCoSo methods: The case of the SUMP Podgorica	Sustainability
Zapolskytė et al. (2022)	Smart urban mobility system evaluation model adaptation to Vilnius, Montreal and Weimar cities	Sustainability
Hajduk (2021)	Multi-Criteria analysis in the decision-making approach for the linear ordering of urban transport based on TOPSIS technique	Energies
Senne et al. (2021)	An index for the sustainability of integrated urban transport and logistics: The case study of São Paulo	Sustainability
Ištoka Otković et al. (2021)	Combining traffic microsimulation modeling and multi-criteria analysis for sustainable spatial-traffic planning	Land
Gompf et al. (2021)	Using Analytical Hierarchy Process (AHP) to introduce weights to social life cycle assessment of mobility services	Sustainability
Morfoulaki and Papathanasiou (2021)	Use of the sustainable mobility efficiency index (SMEI) for enhancing the sustainable urban mobility in Greek cities	Sustainability
Medina et al. (2020)	Defining and prioritizing indicators to assess the sustainability of mobility systems in emerging cities	Advances in Intelligent Systems and Computing
D'Orso et al. (2020)	Using AHP methodology for prioritizing the actions in the transport sector in the frame of SECAPs	Proceedings - 2020 IEEE
Warith et al. (2020)	A new framework for addressing high-level decisions related to sustainable transportation development	International Journal of Sustainable Transportation
Mahmoudi et al. (2019)	Determining the relative importance of sustainability evaluation criteria of urban transportation network	Sustainable Cities and Society
Tripathy et al. (2019)	An innovative approach to assess sustainability of urban mobility - using fuzzy MCDM method	Lecture Notes in Intelligent Transportation and Infrastructure
Felix et al. (2019)	Evaluation model for urban areas to receive integrated revitalization and sustainable mobility projects	Eure
Ghodmare et al. (2019)	Application of the multi attribute utility technique with its for sustainability evaluation of emerging metropolitan city of Nagpur	International Journal of Civil Engineering and Technology
Ramani (2018)	Using indicators to assess sustainable transportation and related concepts	Transportation Research Record
Oses et al. (2018)	Multiple-criteria decision-making tool for local governments to evaluate the global and local sustainability of transportation systems in urban areas: Case study	Journal of Urban Planning and Development
Ngossaha et al. (2017)	Sustainability assessment of a transportation system under uncertainty: An integrated multicriteria approach	IFAC-PapersOnLine

(*Continued*)

TABLE 2 Continued

Citation	Title	Journal
Kolak and Feyzioglu (2016)	Sustainability performance evaluation of transportation networks using MCDM analysis	Lecture Notes in Engineering and Computer Science
Maciel and Freitas (2015)	Sustainable urban mobility: A multicriteria experimental approach conducted in Brazil	Progress in Industrial Ecology
Singh et al. (2014)	Measuring transit oriented development: A spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen	Journal of Transport Geography
Marletto and Mameli (2012)	A participative procedure to select indicators of policies for sustainable urban mobility. Outcomes of a national test	European Transport Research Review
Jeon et al. (2010)	Evaluating plan alternatives for transportation system sustainability: Atlanta Metropolitan region	International Journal of Sustainable Transportation
Castillo and Pitfield (2010)	ELASTIC - A methodological framework for identifying and selecting sustainable transport indicators	Transportation Research Part D: Transport and Environment
Basbas and Papanikolaou (2009)	Evaluation of a sustainable urban transport system through the use of the TRANSECON methodology	International Journal of Sustainable Development and Planning
Campos et al. (2009)	Multi-criteria analysis procedure for sustainable mobility evaluation in urban areas	Journal of Advanced Transportation
Jakimavičius and Burinskiene (2009)	A GIS and multi-criteria-based analysis and ranking of transportation zones of Vilnius city	Technological and Economic Development of Economy
Nijkamp et al. (2007)	Sustainable urban land use and transportation planning: A cognitive decision support system for the Naples metropolitan area	International Journal of Sustainable Transportation
Costa et al. (2005)	Sustainable urban mobility: A comparative study and the basis for a management system in Brazil and Portugal	WIT Transactions on the Built Environment
Spiekermann and Wegener (2003)	Modelling urban sustainability	International Journal of Urban Sciences

because it provides broad interdisciplinary coverage, standardized indexing, and uniform search characteristics, which facilitate reproducibility and comparability of results. Similar transport-related reviews have also relied exclusively on Scopus (Mavlutova et al., 2023; Ruiz Bargueño et al., 2021), supporting the validity of this choice. Nevertheless, we have complemented our literature review by using the Transport Research International Documentation (TRID) database, which specializes in transportation research worldwide. The literature review was conducted using the keywords listed in Table 1. They were defined through an initial exploration that included a review of relevant articles, expert interviews, and case study analyses (Anastasiadou and Gavanas, 2023; da Silva et al., 2022; Yannis et al., 2020; Awasthi et al., 2018; Oses et al., 2018; Campos et al., 2009).

Subsequently, the predefined keywords were searched in both databases, yielding a total of 429 documents. Seven duplicate files were found, so 422 records proceeded to the screening stage. From this set, a first filtering process was conducted, retaining only those articles whose titles and abstracts were explicitly related to urban mobility. In this step, 251 articles were discarded as being outside the scope of the study, since they were primarily associated with energy, construction, economics, education, supply chain, and environment. It should be noted that the entire process was carried out using spreadsheets, in which the articles were manually processed. The remaining 171 records were assessed for eligibility. Given that the purpose of this work is to analyze urban mobility as an integrated system rather than a set of isolated components or actors, the selection criteria prioritized studies offering a holistic and comprehensive perspective. In other words, the review focused on works that addressed all aspects of urban mobility, instead of examining a single aspect in particular. This does not mean that individual components are unimportant; rather, when assessed separately, they fail to capture potential trade-offs or conflicts with the objectives of other dimensions within broader urban mobility. In this sense, 133 were excluded for focusing exclusively on a single dimension of urban mobility: 33 articles addressed freight transport and logistics; 30 on infrastructure and road safety; 27 focused on urban public transport; 14 analyzed mobility from other perspectives; 13 on active mobility, shared mobility, and micro-mobility; 11 on service quality, vehicle technology, and alternative fuels; and five full-text documents were unavailable online. Finally, 38 articles were included in the qualitative synthesis. The complete selection process, including screening and eligibility steps, is presented in Figure 1, which shows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram of the review protocol.

Table 2 shows the final summary of the works analyzed in this study. The selected articles are first analyzed based on bibliometric data, considering the year of publication, the publication journal, and the geographical scope. From each selected article, all the indicators employed were extracted, considering the sustainability dimension, both traditional and emerging, with which they were associated. At this point, it is worth noting that sustainability in urban mobility has evolved beyond the three traditional dimensions (economic, social, and environmental), leading to the identification of emerging dimensions that respond to the specific challenges of modern cities, particularly in contexts of rapid growth (da Silva et al., 2022; Medina et al., 2020). These emerging dimensions arise from the need to integrate factors such as governance, technical and

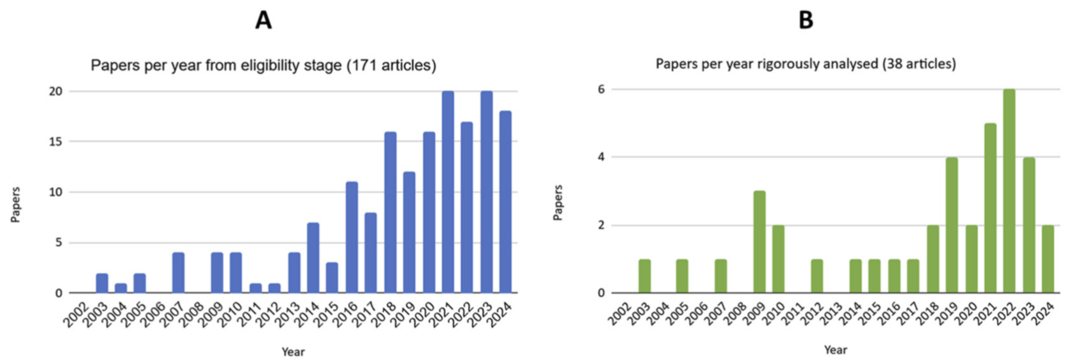

FIGURE 2
Temporal distribution of the number of articles. On the left **(A)**, studies addressing at least one aspect of urban mobility (171 articles); on the right **(B)**, studies analyzing urban mobility in a comprehensive manner (38 articles).

operational performance, and public space use, which were not fully represented in classical sustainability models. Once the indicators were organized, their frequency of appearance across the analyzed documents was determined, allowing us to identify those most commonly employed at present. Likewise, indicators that may not be used very often but consider an aspect of urban mobility that other indicators fail to capture were also taken into account. In addition, a critical review of MCDM methods applied to sustainable urban mobility was conducted, examining which methods are most frequently used when making decisions about a city's mobility system. As these data were collected, new knowledge gaps were identified that may guide future research in underexplored areas. Finally, through expert collaboration and based on the findings of this study, a set of indicators is proposed to analyze the sustainability of mobility in medium-sized Latin American cities.

4 Main findings

The articles analyzed in this paper focus on the management and planning of sustainable urban mobility using various sets of indicators, as well as different MCDM methods. Next, a bibliometric analysis of the selected articles is presented, followed by an identification of the indicators and MCDM methods used to assess the sustainability of urban mobility.

4.1 Bibliometric analysis

At this point, an initial finding emerges regarding the number of articles identified through the review process, which can be considered relatively low (38 articles). However, beyond the potential limitations inherent to any literature review, this outcome may also reflect the complexity of assessing sustainability in urban mobility when it is examined as an integrated whole. For this reason, many authors may be focusing on studying only one aspect of mobility, which is not entirely accurate considering that mobility is a complex and interconnected system. It is worth mentioning that this situation has already been reflected in studies conducted by Zapolskytė et al. (2022), Ayadi et al. (2024), and Suprayoga et al. (2020).

When evaluating the year of publication of the articles, it is clear that the topics analyzed are booming. Figure 2 shows the growth in the number of publications, with a particular increase in the study of urban mobility through the use of indicators since 2014. It should be noted that, in the case of Figure 2A, the 171 articles considered in the eligibility stage were taken into account, including works covering some or all aspects of urban mobility. When only the 38 final articles are analyzed, the trend is similar; however, there is a decrease in the number of articles presented in 2024 (see Figure 2B).

In addition, it was observed that most of the articles included in this literature review were published in *Sustainability* (seven articles), followed by *Sustainable Cities and Society* and the *International Journal of Sustainable Transportation*, with three articles each (see Figure 3). These are followed by *Energies*, the *Journal of Advanced Transportation*, and the *Journal of Urban Planning and Development*, each contributing two articles. The remaining journals include only one publication related to the topic under study.

The most relevant keywords in the set of papers analyzed can be seen in Figure 4. It shows that the term "multi-criteria decision making" stands out as a keyword in 75% of the studies reviewed, followed by "sustainable mobility or transportation" (54%) and "urban mobility or transport" (43%). It is worth mentioning that there is a group of articles that have worked on the Transit-Oriented Development (TOD) index, which is related to Spatial Multi-Criteria Analysis (SMCA) and the use of Geographic Information Systems (GIS), which is why they are represented in Figure 4.

When analyzing the origin and cases of application of the selected works, it was found that 50% focus on European countries, 26% on American nations, 21% on Asian ones, only 3% on African countries, and no works were detected in Oceania (see Figure 5). It should be noted that only two countries are represented among the American countries: Brazil and the United States (da Silva et al., 2022; Senne et al., 2021; Warith et al., 2020; Felix et al., 2019; Ramani, 2018; Maciel and Freitas, 2015; Jeon et al., 2010; Campos et al., 2009; Costa et al., 2005). It should be noted that four studies are not associated with a specific geographical region.

On the other hand, it is noteworthy that the cities most represented in the studies are those considered mega or big, with

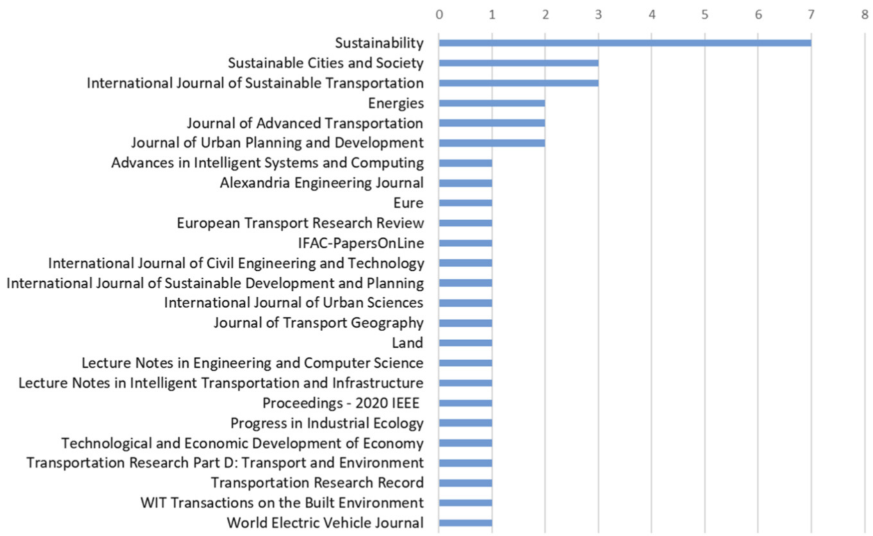

FIGURE 3
Ranking of the journals where the articles of this literature review are published.

FIGURE 4
Word cloud of keywords used in the reviewed articles.

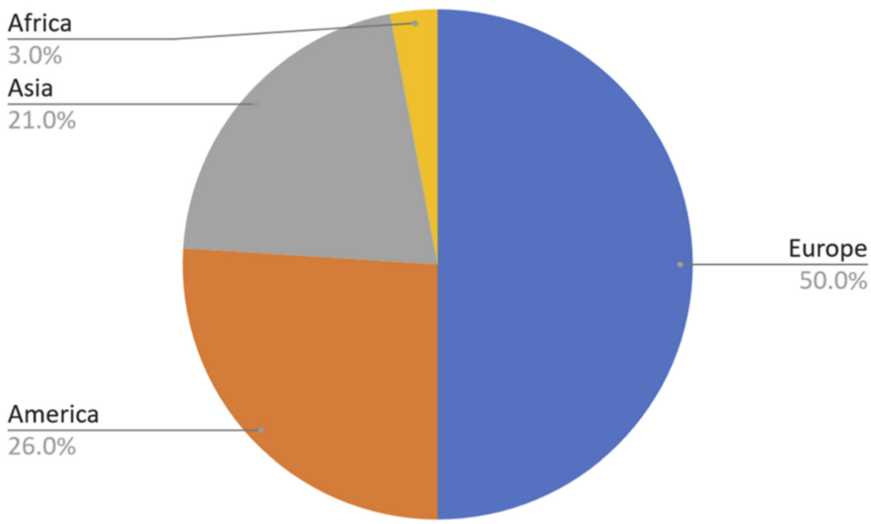

FIGURE 5
Geographical distribution of the reviewed articles by continent.

74%, followed by medium-sized cities with 22% representation and small cities with only 4%. This highlights the lack of this type of study in medium-sized and small cities, mainly in Latin American, African, and Oceanic countries. This is considered a research gap since these cities have growth potential and currently face mobility problems that should be addressed before they grow, especially medium-sized cities.

4.2 Indicators for assessing urban mobility

It should be noted that assessing progress toward sustainable urban mobility requires measuring current performance in relation to past results. This information is essential for anticipating how different development scenarios or strategies may influence future outcomes. In this regard, indicators are required, which can be defined as a variable or a combination of selected variables to represent a characteristic of interest, allowing it to be evaluated (Gudmundsson et al., 2016).

The selected articles use different sets of indicators depending on the objectives of the work and the different aspects of sustainable urban mobility that they wish to evaluate. In this regard, as mentioned above, we identified two main approaches: one related to measuring the level of mobility sustainability and the other focused on determining the level of Transit-Oriented Development (TOD). In addition, we highlight that we have identified some studies that work with the requirements set out in Norma ISO 37120:2018 (Sustainable cities and communities: Indicators for city services and quality of life), which provides key indicators for measuring the performance of services and quality of life in cities, including mobility (Hajduk, 2021; Tripathy et al., 2019). It is difficult to establish a single set of indicators conclusively, since all studies evaluate the availability of data, as well as whether it is adequate for assessing the parameters of the city or region under study. It should also be borne in mind that considering a large number of indicators can be very cumbersome when they are evaluated by experts, who establish their weights at a later stage. However, it is possible to identify common and relevant sets of indicators that are frequently used.

These indicators can also be considered by a composite index that groups them together in order to obtain a single value by aggregating a certain number of standardized indicators and their weightings for each city, as presented in Morfoulaki and Papathanasiou (2021), Warith et al. (2020), Tripathy et al. (2019), Jeon et al. (2010), and Campos et al. (2009). These types of indices allow for quick comparisons of the sustainability level of urban mobility. For example, Warith et al. (2020) propose the Dynamic Index for National Advancement (DINA), which is a composite index developed with the idea of incorporating sustainability into decision-making processes. However, there may be some controversy depending on how the index is defined, as there may be trade-offs between indicators when aggregating them. This situation could lead to a misleading final value for the sustainability level (Danielis et al., 2017).

At this point, it is interesting to note that both sustainable mobility indicators and TOD indicators aim to promote sustainable urban development. However, there are subtle differences between them: the former focuses on assessing the overall sustainability of urban mobility systems, while TOD indicators seek to evaluate the effectiveness of TOD strategies adopted in a specific area. In this sense, sustainability indicators cover a greater number of dimensions, considering traditional ones (economic, environmental, and social) as well as emerging ones (quality of service, technical, urban spatial, among others). On the other hand, TOD indicators emphasize land use, the integration of residential, commercial, and recreational spaces, and proximity to public transportation hubs. Hence, it could be said that sustainable mobility indicators provide a comprehensive view of the effectiveness of transportation systems in achieving sustainability goals in a city, while TOD indicators focus on the specific characteristics of urban developments that facilitate the use of public transportation and reduce car dependency. For this reason, the following sections present indicators for assessing sustainability and the level of TOD separately.

4.2.1 Indicators for assessing sustainable urban mobility

In 1987, the Brundtland Report defined sustainability as development that meets the needs of the present without compromising the ability of future generations to satisfy their own needs (United Nations, 1987). Based on this, sustainable urban mobility can be defined as described in the introduction, namely as mobility that meets people's travel needs without compromising the three traditional dimensions of sustainability (environmental, social, and economic). For this reason, studies that focus on analyzing sustainability mainly group indicators into these three broad dimensions (Gulcimen et al., 2023; Siksnelyte-Butkiene and Streimikiene, 2022; da Silva et al., 2022; Zapolskytė et al., 2022; Ištoka Otković et al., 2021; Gompf et al., 2021; Morfoulaki and Papathanasiou, 2021; Medina et al., 2020; D'Orso et al., 2020; Warith et al., 2020; Ghodmare et al., 2019; Mahmoudi et al., 2019; Oses et al., 2018; Ngossaha et al., 2017; Kolak and Feyzioglu, 2016; Marletto and Mameli, 2012; Campos et al., 2009; Nijkamp et al., 2007; Costa et al., 2005; Spiekermann and Wegener, 2003). However, some studies not only include the three dimensions of sustainability but also consider others, such as technical (da Silva et al., 2022); smart infrastructure measures (Zapolskytė et al., 2022); functional and spatial-urban (Ištoka Otković et al., 2021); operational and mobility system effectiveness and land use (Medina et al., 2020); urban model and vehicle fleet characteristics (Oses et al., 2018); transportation system effectiveness (Jeon et al., 2010), and urban mobility management (Costa et al., 2005). Likewise, some only address certain dimensions, such as Basbas and Papanikolaou (2009), which only consider economic and social dimensions.

Based on a thorough analysis of the selected articles, we identified a set of indicators that can be considered robust for analyzing the sustainability of urban mobility in different cities. This set, presented in Table 3, was derived from 404 indicators extracted from the reviewed studies and grouped according to their relevance and frequency of use. The indicators were selected because they meet some key criteria: they are directly related to the sustainability of urban mobility, they are widely used, they cover key aspects of mobility, and they are comparable across different contexts. It should be noted that in some cases, the same indicator may be associated with more than one dimension, for example,

TABLE 3 Indicators used to assess the sustainability level of urban mobility, their associated sustainability dimension, and the studies in which they appear.

Dimension	Indicator	Article
Environmental	Air quality index	Gompf et al., 2021; Warith et al., 2020; Oses et al., 2018; Marletto and Mameli, 2012; Spiekermann and Wegener, 2003
	Carbon monoxide (CO) emissions	da Silva et al., 2022; Ištoka Otković et al., 2021; Kolak and Feyzioglu, 2016; Marletto and Mameli, 2012
	Nitrogen oxide (NOx) emissions	da Silva et al., 2022; Ištoka Otković et al., 2021; Medina et al., 2020; Kolak and Feyzioglu, 2016; Marletto and Mameli, 2012; Jeon et al., 2010; Spiekermann and Wegener, 2003
	Volatile organic compounds (VOC) emissions	da Silva et al., 2022; Ištoka Otković et al., 2021; Marletto and Mameli, 2012; Jeon et al., 2010
	Particulate matter (PMx) emissions	Medina et al., 2020; Kolak and Feyzioglu, 2016; Marletto and Mameli, 2012; Spiekermann and Wegener, 2003
	Noise pollution	da Silva et al., 2022; Gompf et al., 2021; Medina et al., 2020; Mahmoudi et al., 2019; Oses et al., 2018; Marletto and Mameli, 2012; Costa et al., 2005
	Carbon dioxide (CO_2) emissions	Gulcimen et al., 2023; Medina et al., 2020; Mahmoudi et al., 2019; Oses et al., 2018; Kolak and Feyzioglu, 2016; Spiekermann and Wegener, 2003
	Fossil fuel consumption	Gulcimen et al., 2023; da Silva et al., 2022; Ištoka Otković et al., 2021; Spiekermann and Wegener, 2003
	Non-fossil fuel consumption	Gulcimen et al., 2023; da Silva et al., 2022; Ištoka Otković et al., 2021; Spiekermann and Wegener, 2003
Social	Vehicle accidents with victims	Gulcimen et al., 2023; Siksnelyte-Butkiene and Streimikiene, 2022; da Silva et al., 2022; Gompf et al., 2021; Morfoulaki and Papathanasiou, 2021; D'Orso et al., 2020; Oses et al., 2018; Kolak and Feyzioglu, 2016; Costa et al., 2005; Spiekermann and Wegener, 2003
	Vehicle accidents with injuries	Gulcimen et al., 2023; da Silva et al., 2022; Gompf et al., 2021; Morfoulaki and Papathanasiou, 2021; D'Orso et al., 2020; Oses et al., 2018; Kolak and Feyzioglu, 2016; Costa et al., 2005; Spiekermann and Wegener, 2003
	Vehicle accidents with pedestrians	Gulcimen et al., 2023; da Silva et al., 2022; Gompf et al., 2021; Morfoulaki and Papathanasiou, 2021; D'Orso et al., 2020; Oses et al., 2018; Kolak and Feyzioglu, 2016; Costa et al., 2005; Spiekermann and Wegener, 2003
	Quality of public transportation	Gulcimen et al., 2023; da Silva et al., 2022; Morfoulaki and Papathanasiou, 2021; Medina et al., 2020; D'Orso et al., 2020; Oses et al., 2018; Kolak and Feyzioglu, 2016; Marletto and Mameli, 2012; Campos et al., 2009; Spiekermann and Wegener, 2003
	Accessibility to public transportation	da Silva et al., 2022; Gompf et al., 2021; Morfoulaki and Papathanasiou, 2021; Medina et al., 2020; D'Orso et al., 2020; Mahmoudi et al., 2019; Ngossaha et al., 2017; Campos et al., 2009; Costa et al., 2005
	Accessibility for vulnerable users	da Silva et al., 2022; Gompf et al., 2021; Medina et al., 2020; D'Orso et al., 2020; Ngossaha et al., 2017
Economic	Public transport operational costs	Gulcimen et al., 2023; da Silva et al., 2022; Medina et al., 2020; Spiekermann and Wegener, 2003
	Public transport maintenance costs	Gulcimen et al., 2023; Medina et al., 2020; Spiekermann and Wegener, 2003
	Public transport operator benefits	Spiekermann and Wegener, 2003
	Cost of public transportation fares	da Silva et al., 2022; Gompf et al., 2021; Medina et al., 2020; Ngossaha et al., 2017; Marletto and Mameli, 2012
	Parking fees	da Silva et al., 2022; Medina et al., 2020; Oses et al., 2018
	Fuel price	Gulcimen et al., 2023; Mahmoudi et al., 2019; Oses et al., 2018; Marletto and Mameli, 2012
	Investments in transport infrastructure	Costa et al., 2005
Operational and technical	Level of service	da Silva et al., 2022; Ištoka Otković et al., 2021; Medina et al., 2020; Warith et al., 2020; Marletto and Mameli, 2012; Nijkamp et al., 2007
	Average age of the vehicle fleet	da Silva et al., 2022; Medina et al., 2020
	Segmentation of the vehicle fleet	Siksnelyte-Butkiene and Streimikiene, 2022; da Silva et al., 2022; Medina et al., 2020
	Loading and unloading areas	Oses et al., 2018
	Quality of roads	Kolak and Feyzioglu, 2016
	Smart streets	da Silva et al., 2022; Zapolskytė et al., 2022
	Shared mobility	Zapolskytė et al., 2022; Oses et al., 2018

(*Continued*)

TABLE 3 Continued

Dimension	Indicator	Article
Spatial-urban	Length of bicycle paths	da Silva et al., 2022; Ištoka Otković et al., 2021; Morfoulaki and Papathanasiou, 2021; Medina et al., 2020; Oses et al., 2018; Marletto and Mameli, 2012; Campos et al., 2009
	Length of pedestrian infrastructure	Ištoka Otković et al., 2021; Morfoulaki and Papathanasiou, 2021; Medina et al., 2020; Marletto and Mameli, 2012
	Surface for roads	Oses et al., 2018
	Population density	Medina et al., 2020; Costa et al., 2005
	Population growth rate	Warith et al., 2020; Costa et al., 2005
	Number of parking spaces	Ištoka Otković et al., 2021; Gompf et al., 2021; Medina et al., 2020

pollutant emissions can be classified under the environmental or social one, depending on whether the focus is ecological or health-related. Likewise, indicators such as public transport service quality are inherently multidimensional, encompassing vehicle allocation, frequency, and travel time. Although certain indicators may be difficult to measure, they were retained because they contribute to a balanced and comprehensive understanding of sustainability in urban mobility. This selection process guarantees that the indicators presented in Table 3 are not only among the most frequently cited in the literature but also encompass the diverse aspects of urban mobility in contemporary cities. For instance, the inclusion of the number of loading and unloading zones addresses urban logistics, while the indicator related to investment in transportation infrastructure is associated with the government.

As can be seen in Table 3, there are nine indicators associated with the environmental dimension, which are mainly related to the amount of pollutant and greenhouse gas emissions produced by the transport sector. Noise pollution and the consumption of fossil fuels or non-fossil fuels are also included in the environmental aspect. Although these data are difficult to measure and sometimes expensive due to the instruments required, they can be obtained through estimates such as emissions inventories or through the use of traffic microsimulation tools, as done by Ištoka Otković et al. (2021).

Regarding the social dimension, we highlight six indicators mainly associated with safety through the evaluation of accidents; the quality of public transport service, which includes the number of vehicles used to provide services per number of inhabitants, frequency, and travel time; and accessibility, first to public transport, considering the percentage of inhabitants who have a bus stop less than 500 m away, and second to transport services for vulnerable people, considering the number of units that have specific seats/places for them.

To assess the economic dimension, seven indicators were selected, including the costs incurred by the government and companies for the operation and maintenance of public transport. The profits made by public transport operators are also included. In addition, indicators related to the price of public transport fares, private vehicle parking, and fuel are included. It should be noted that in the case of public transport fares, it would also be possible to evaluate how much a household spends on public transportation and on private transport, as considered in Marletto and Mameli (2012). The cost of maintaining mobility infrastructure is included, which includes the cost of maintaining roads as a central axis, both paved and dirt roads. It should be noted that the latter are common in Latin American cities, especially as one moves away from the city center.

In light of the studies analyzed in this review, we identified the need to incorporate two additional dimensions (operational and technical, and spatial-urban) to the three traditional dimensions of sustainability already presented. These emerging dimensions are not intended to replace existing ones, but rather to organize and interpret a set of indicators that do not easily align with the classical framework. In this sense, we have the operational and technical dimension, with seven indicators related to the level of street service (considering queue length and mean delays), the characteristics of the vehicle fleet (age, segmentation by vehicle and fuel type), the existence of loading and unloading zones associated with last-mile distribution, street quality (related to maintenance and traffic conditions), street intelligence (digitization of public transport, real-time information, smart parking), and shared mobility (evaluating shared micro-vehicle or carpooling systems). The spatial-urban dimension reflects the growing recognition in the literature that the configuration and use of public space is central to sustainable mobility outcomes (Medina et al., 2020; Ištoka Otković et al., 2021). This concept encompasses not only technical infrastructure but also integrates the relationship between land use and the ability to create efficient, safe, and livable urban environments. This dimension includes indicators such as the length of bicycle lane networks, pedestrian infrastructure, population density and growth rate, and the proportion of land allocated to streets and parking. While it might have been possible to consider other dimensions specifically, such as public transport, safety, or logistics, these are already represented in the other dimensions through indicators such as accessibility to public transport, accident rates, and loading and unloading zones for urban logistics. In contrast, operational/technical aspects and the use of public space emerged from our review as cross-cutting issues that are not sufficiently reflected in the traditional trilogy, justifying their treatment as separate dimensions.

When analyzing the dimensions according to the number of indicators associated with each one, the environmental dimension ranks first with nine indicators, followed by the economical and the operational/technical ones with seven each, and finally the social and the spatial-urban dimensions with six indicators. Furthermore, analysis of the frequency with which indicators for each

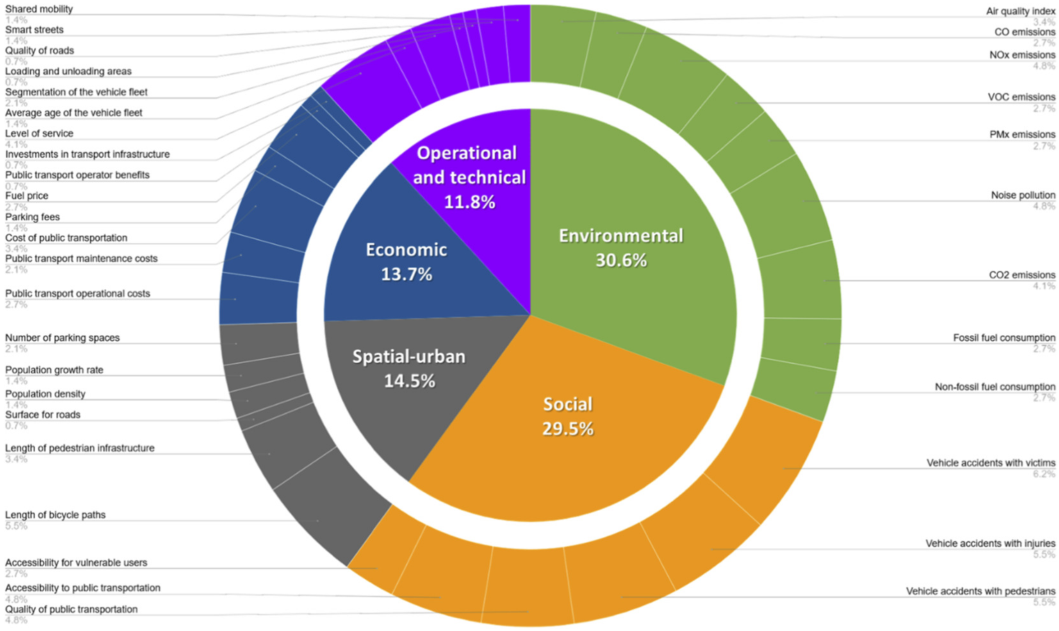

FIGURE 6
Diagram of the percentage of occurrence of each indicator in the literature, considering the associated dimension.

dimension are used shows that the dimension most frequently applied is also the environmental one (30.6%), largely due to the widespread use of indicators related to pollutant emissions and noise levels (see Figure 6). This is closely followed by the social dimension (29.5%), followed by the spatial-urban (14.5%), the economic (13.7%), and the operational and technical dimension represents 11.8%.

Indicators for analyzing sustainable urban mobility provide structured tools for examining current conditions and exploring potential future scenarios. They are designed to capture the multiple dimensions that influence sustainable mobility systems. In this study, the selection of 35 indicators resulted from a structured process. First, all indicators available in the academic literature and international frameworks were compiled and analyzed. Their frequency of appearance and their relevance to the different dimensions of urban mobility were assessed to identify those most consistently used to evaluate sustainable mobility performance. Importantly, the selection process did not rely solely on frequency. Conceptual equivalence across studies was also examined to avoid redundancy and ensure consistency. For example, the studies of Ištoka Otković et al. (2021), Kolak and Feyzioglu (2016), and Jeon et al. (2010) disaggregate emissions by pollutant type, whereas the work of Marletto and Mameli (2012) refers more generally to transport-related pollutant emissions. These cases were treated as conceptually equivalent, and the broader formulation was considered to complement studies that provided a more detailed disaggregation. A similar approach was applied to congestion-related measures, where studies like da Silva et al. (2022), Medina et al. (2020), Mahmoudi et al. (2019), and Marletto and Mameli (2012) include congestion as an indicator, while the study of Ištoka Otković et al. (2021) operationalizes the same concept through the level of service of urban streets. These were grouped to reflect their shared underlying construct. Additionally, some indicators were incorporated because they addressed critical aspects of urban mobility that are often underrepresented in existing frameworks. For instance, last-mile freight transport was included through the consideration of loading and unloading areas, and the distribution of public space was examined by assessing the proportion allocated to streets. These additions ensured that the final set of indicators captured both widely recognized dimensions and all aspects and actors involved in urban mobility. Together, these 35 indicators support a comprehensive understanding of existing mobility dynamics and their implications across sustainability dimensions. By clarifying the current situation, they help identify opportunities for improvement and inform the development of future strategies. Such indicators are particularly relevant for entities or organizations seeking to design or redesign urban mobility systems with an integrative and inclusive sustainability perspective. Medium-sized Latin American cities, for example, can use these tools to establish a robust diagnostic baseline and subsequently develop action plans to advance sustainable urban mobility.

4.2.2 Indicators for assessing TOD-ness (TOD level)

Transit-oriented development (TOD) can be defined as a form of strategic urban planning that presents a balanced combination of land uses and an environment that is accessible on foot, by bicycle, or by public transportation, seeking to reduce the use of private cars (Singh et al., 2018). As such, the concept of TOD emerged in the late 1980s and is an approach that aims to improve accessibility, reduce traffic congestion, and minimize the environmental impacts associated with urban sprawl by making sustainable modes of transportation more convenient and desirable to people (Ibraeva et al., 2020). The articles by Abdullah et al. (2024), Anwar et al. (2024), Ibrahim et al. (2023), Uddin et al. (2023), Felix et al. (2019),

TABLE 4 Indicators used to assess the level of Transit-Oriented Development (TOD), their relationship to TOD dimension, and the studies in which they appear.

Dimension	Indicator	Article
Urban density	Population density	Abdullah et al., 2024; Anwar et al., 2024; Ibrahim et al., 2023; Uddin et al., 2023; Felix et al., 2019
	Commercial density	Abdullah et al., 2024; Anwar et al., 2024; Ibrahim et al., 2023; Uddin et al., 2023; Singh et al., 2014
	Residential density	Ibrahim et al., 2023; Singh et al., 2014
	Employment density	Ibrahim et al., 2023; Uddin et al., 2023; Singh et al., 2014
Design of urban space	Land-use mixedness	Abdullah et al., 2024; Anwar et al., 2024; Ibrahim et al., 2023; Uddin et al., 2023; Singh et al., 2014
	Intersection density	Abdullah et al., 2024; Anwar et al., 2024; Uddin et al., 2023; Singh et al., 2014
	Walkable/ cyclable paths	Anwar et al., 2024; Uddin et al., 2023; Singh et al., 2014
Diversity of land-use	Diversity of land-use	Abdullah et al., 2024; Anwar et al., 2024; Ibrahim et al., 2023, Uddin et al., 2023; Felix et al., 2019; Singh et al., 2014

and Singh et al. (2014) evaluate the level of implementation of a TOD strategy using indicators mainly aimed at assessing urban density, land-use diversity, and urban space design. Table 4 presents the most commonly used indicators in the selected documents. These indicators are valuable for planning and evaluating more sustainable urban development scenarios around public transport nodes, as they focus only on a specific area of study and not on the analysis of urban mobility as a whole.

In assessing the TOD level, urban density is identified as a topic of utmost importance. Therefore, it is not considered as an overall value, but rather the aim is to describe this density in more than one component in order to obtain a realistic analysis of the situation. In this sense, the urban density dimension evaluates not only population density but also the density of activities carried out in the area near the evaluated public transport points, such as commercial and residential density. On the other hand, the design of urban space dimension seeks to analyze the characteristics of the built environment, evaluating walkability and the use of non-motorized transportation. This dimension also analyzes the combination of residential land use with other types of land use, using the land-use mixedness index (Anwar et al., 2024). Finally, the diversity of the land-use index is used to evaluate the heterogeneity of all types of land use present in the study area, not limited to the relationship between residential and non-residential (Ibrahim et al., 2023).

4.3 Multi-criteria decision making (MCDM) methods for assessing urban mobility

MCDM methods are tools that enable decision-makers to solve decision problems in which different points of view must be considered, prioritizing important criteria, reducing uncertainty, and increasing the quality of decisions (Maciel and Freitas, 2015). In this sense, MCDM methods are particularly useful when faced with decisions based on options that have multiple attributes, often in conflict with each other (Almashhour et al., 2023), for example, to facilitate a decision-making process when there are multiple criteria in the field of sustainable mobility development (Demir et al., 2022). According to Almashhour et al. (2023), MCDM methods are suitable for evaluating sustainable urban mobility issues and associated decision-making due to the consideration of the opinions of different stakeholders and the dimensions of sustainability.

When analyzing the selected articles, we find that several MCDM methods are applied, which aligns with Anastasiadou's (2021) statement, highlighting that there is no wrong MCDM method to use, but that the Analytic Hierarchy Process (AHP) and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) are the most widely used in the transport sector. Figure 7 illustrates this trend, showing that AHP, both in its traditional version and in the Fuzzy Analytic Hierarchy Process (FAHP), and TOPSIS are the most frequently used. Although the Spatial Multi-Criteria Analysis (SMCA) method is frequently used, it is related to the analysis of the TOD level, not to the overall analysis of urban mobility, as we will explain later.

As can be seen in Figure 7, the AHP is one of the most commonly used MCDM methods applied to urban mobility. The AHP includes a clear hierarchical decision structure, which is useful for problems involving multiple criteria and interest groups, a pairwise comparison, and a priority aggregation process (Saaty, 1988). The FAHP is an extension of the former that incorporates fuzzy set theory to address the uncertainty inherent in human judgment during the decision-making process (Liu et al., 2020). Numerous studies apply these methods, including Senne et al. (2021), da Silva et al. (2022), Zapolskytė et al. (2022), Ištoka Otković et al. (2021), Gompf et al. (2021), D'Orso et al. (2020), Castillo and Pitfield (2010), Campos et al. (2009), and Costa et al. (2005) for and Abdullah et al. (2024), Nodari et al. (2022), Medina et al. (2020), Felix et al. (2019), Oses et al. (2018), and Ngossaha et al. (2017) employ FAHP. Furthermore, Mahmoudi et al. (2019) use the methodology developed by Rezaei (2015) called the Best Worst Method (BWM) to identify the importance of criteria for evaluating the sustainability of the urban transport network of an Iranian city. This method requires fewer pair comparisons than AHP; its results are more consistent, and the integration of fuzzy set theory helps to incorporate subjectivity and uncertainty (Kumar and Anbanandam, 2022). Although we have only identified one study that applies BWM in this review, this method is being widely applied in its fuzzy version in specific areas of urban mobility, such as urban freight transport (Grassi et al., 2025).

TOPSIS is another widely used method, which is used to rank different alternatives based on their proximity to an ideal solution (Hwang and Yoon, 1981). The idea is that the chosen alternative has

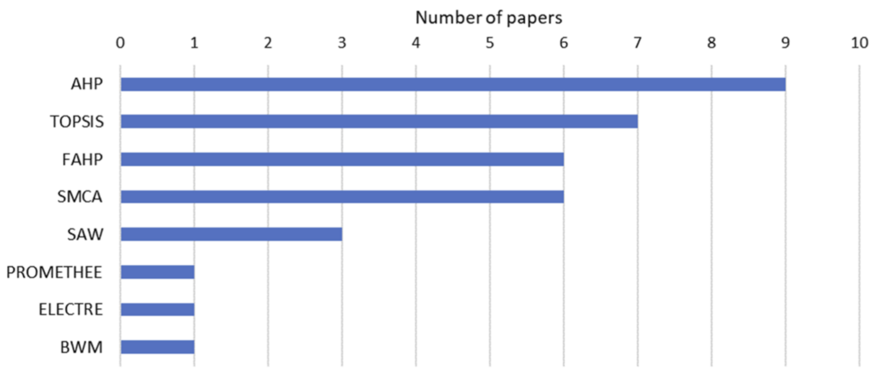

FIGURE 7
Number of publications using each MCDM method in the reviewed literature. Acronyms correspond to: Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy Analytic Hierarchy Process (FAHP), Spatial Multi-Criteria Analysis (SMCA), Simple Additive Weighting (SAW), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Elimination et Choice Translating Reality (ELECTRE), and Best–Worst Method (BWM).

the shortest geometric distance to the positive ideal solution and the furthest distance to the negative ideal solution. Of the selected works, Hajduk (2021) and Siksnelyte-Butkiene and Streimikiene (2022) use TOPSIS. This method is also employed by Abdullah et al. (2024), Zapolskytė et al. (2022), da Silva et al. (2022), Kolak and Feyzioglu (2016), and Jakimavičius and Burinskiene (2009), but coupled with other methods. In the case of Abdullah et al. (2024), in addition to using FAHP and TOPSIS, they employ the Simple Additive Weighting (SAW), the Weighted Aggregated Sum Product Assessment (WASPAS), the Euclidean Distance-based Aggregating and Selection (EDAS), and the MultiObjective Optimization by Ratio Analysis (MOORA). Jakimavičius and Burinskiene (2009) use SAW as well as TOPSIS. Zapolskytė et al. (2022) utilize AHP, TOPSIS, and SAW, while Kolak and Feyzioglu (2016) employ TOPSIS together with the Choquet integral and the Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH), which is a Multi-Attribute Utility Theory (MAUT) method. On the other hand, the case of Almashhour et al. (2023) is based on the Analytic Network Process (ANP) and the Delphi method. Moreover, Demir et al. (2022) employ the Fuzzy Full Consistency Method (F-FUCOM) to determine the weightings and the Fuzzy Combined Compromise Solution (F-CoCoSo) method to classify the alternatives. Ghodmare et al. (2019) apply the Multi Attribute Utility Technique, aligned with the rational actor model, to assess sustainability in transport and land use for emerging metropolitan areas.

At this point, it can be said that methods such as AHP, SAW, or TOPSIS are simple and transparent, which makes them useful when decision-makers need to compare alternatives using indicators that have already been quantified using other analytical tools. However, the uncertainty involved in human judgment when evaluating different indicators must be considered (Gulcimen et al., 2023; Nodari et al., 2022). In this regard, fuzzy logic (e.g., FAHP, F-FUCOM, F-CoCoSo) or grey systems theory are particularly valuable when seeking to improve consistency and incorporate uncertainty more explicitly (Liu et al., 2011). Another issue to consider is how methods are handled as indicators or alternatives increase. In this case, AHP can become cumbersome and complex if there are too many pairwise comparisons, increasing the risk of inconsistency (da Silva et al., 2022; Kolak and Feyzioglu, 2016). In this sense, it is interesting to highlight the BWM approach, as it also uses a paired comparison approach, but only between the worst and best selected indicators and the rest of them, which reduces the number of paired comparisons. It can also be used in its fuzzy version to reduce subjectivity (Mahmoudi et al., 2019). Meanwhile, TOPSIS is often chosen for its mathematical simplicity and speed of calculation, allowing a large number of alternatives to be evaluated quickly. However, this method is considered particularly sensitive to small changes in the weights of the indicators, causing significant variations in the prioritization of alternatives (Abdullah et al., 2024; Hajduk, 2021).

On the other hand, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and ELECTRE (Elimination et Choice Translating Reality) are known as outranking methods. These approaches offer advantages when criteria are contradictory or when non-compensatory decisions are needed, meaning that extremely poor performance in one criterion cannot be simply compensated for by high scores in others, which can occur when using AHP. Morfoulaki and Papathanasiou (2021) used PROMETHEE to evaluate Greece's sustainable urban mobility plan. PROMETHEE was developed by Brans et al. (1986), and according to Oubahman and Duleba (2021), the method can be characterized by three pillars: the enrichment of the preference structure involving different preference functions, the enrichment of the dominance relationship between alternatives for each criterion, and decision support after partial ranking (PROMETHEE I) or complete ranking (PROMETHEE II). Otherwise, ELECTRE was developed by Bernard Roy (Roy, 1991), and is used in the work of Maciel and Freitas (2015) to generate a ranking of Brazilian cities based on sustainable mobility indicators. ELECTRE is used in classification problems, where data may be imprecise, uncertain, or poorly defined. Although outranking methods are not usually the most popular when addressing sustainable urban mobility issues, they can be a good alternative in complex contexts where there are multiple stakeholders and substantial ambiguity. It is also important to note that whether TOPSIS or outranking methods are used, the weighting of the indicators must be done beforehand using another approach, which is usually AHP or BWM.

Another methodology identified is the Spatial Multi-Criteria Analysis (SMCA) or Spatial Multiple Criteria Assessment (SMCA), used specifically in cases where TOD levels are analyzed. This tool combines the principles of multi-criteria analysis with the capabilities of Geographic Information Systems (GIS) (Ibrahim et al., 2023; Nodari et al., 2022; Ramani, 2018). In this sense, this tool allows geographic data to be visualized through a computer platform (Singh et al., 2014). In particular, this method has been used in the works of Anwar et al. (2024), Ibrahim et al. (2023), Uddin et al. (2023), Nodari et al. (2022), Ramani (2018), and Singh et al. (2014) to address spatial decision-making problems focused on the planning and management of sustainable urban mobility.

At this point, based on the literature review, it is interesting to note that the AHP and TOPSIS methods are among the most widely used in cases of sustainable mobility assessment. The AHP and BWM methods stand out as the most commonly used for prioritizing and weighting indicators, while TOPSIS, PROMETHEE, and ELECTRE are used to rank alternatives. Likewise, the use of different methods in the same study stands out, with the aim of evaluating their performance as well as their hybridization. Although Anastasiadou (2021) highlights VIKOR (Vlsekrzterijumska Optimizacija I Kompromisno Resenje) as one of the most widely used methods, we have not detected any studies within the selection made that use this methodology.

As discussed, various MCDM methods are widely applied in the evaluation of sustainable urban mobility, with their main contribution lying in supporting the decision-making process once all relevant information on the different indicators has been compiled. However, such data are not always easily or directly obtainable. In many cases, particularly in contexts with limited data availability, such as several Latin American cities, it becomes necessary to rely on transport models, traffic microsimulations, manual data collection, statistical records, emissions inventories, air quality modeling, and other methodologies to generate the primary information required for each indicator under analysis. For instance, Ištoka Otković et al. (2021) employ VISSIM, a traffic microsimulation software that enables the generation of certain primary data. SUMO may also be used as an open-source alternative in financially constrained contexts (Rossit et al., 2025). From this perspective, the suitability of each MCDM method depends on how it manages the evaluation and aggregation of the urban mobility indicators considered within the decision-making process.

In general, the literature shows that there is no single MCDM method that is universally optimal for assessing sustainable urban mobility. Rather, the suitability of each approach depends on the complexity of the transport system, the quality of available data, the number of indicators and alternatives being assessed, and the context of decision-making. In this regard, hybrid approaches, which combine methods for weighting and prioritizing alternatives, seem particularly promising for addressing the multifaceted nature of urban mobility challenges. Likewise, it can be considered that in contexts where data are incomplete or noisy, a frequent situation in cities in developing countries, outranking methods or those incorporating fuzzy logic or grey systems theory may offer greater robustness than purely compensatory methods.

5 Future research challenges

This section highlights future research challenges that, based on the main findings in the literature, need to be addressed to generate a more integrated understanding of sustainable urban mobility assessment. We have summarized the topics to be covered in six challenges, explaining each one.

5.1 Research challenge 1

Apply indicators and MCDM methods to assess the sustainability of urban mobility in medium-sized cities in Latin America, considering their specific characteristics. We have observed a strong geographical concentration in the studies analyzed. Most applications of indicators and MCDM methods to assess sustainability in urban mobility are found in Europe, America, and Asia, particularly in large cities of developed countries. Only a few cases were identified in Latin America, and exclusively in Brazil. This geographic bias limits the generalizability of current findings and highlights the need to expand research to medium-sized cities in Latin American countries, which usually have growth potential, and exhibit different mobility patterns and vehicle fleet characteristics.

5.2 Research challenge 2

Develop a standardized methodological framework for assessing the sustainability of urban mobility by identifying a core set of indicators aligned with existing international guidelines but adaptable to different urban environments, and by establishing criteria for selecting the most appropriate MCDM method according to the evaluation objectives, data availability, and decision-making context. We have also found that there are a few studies related to the comprehensive assessment of urban mobility, which could be associated with the fact that mobility is a complex system. Most studies focus on one aspect of mobility, such as public transport, micromobility, or active mobility. In this sense, one of the main challenges identified is the absence of a standardized framework for assessing sustainable urban mobility as an integrated system. Although several international initiatives propose guidelines and indicator families, such as the Sustainable Urban Mobility Indicators (SUMI) or the ISO 37120/37122 standard for sustainable and smart cities, there is still no widely adopted methodological standard specifically tailored to the comprehensive evaluation of sustainable urban mobility. As a result, studies tend to focus on isolated components (e.g., public transport, micromobility, or active mobility) and rely on heterogeneous sets of indicators and MCDM methods, which limits comparability across cities and contexts.

5.3 Research challenge 3

Compare the results achieved through the use of different MCDM techniques applied to the assessment of sustainable urban mobility to identify methodological convergences, divergences, and implications for decision-making. Our results also show that, although multiple MCDM methods are used in the literature, there is a lack of comparative analyses examining how different techniques influence the weighting of indicators or the prioritization of alternatives. This gap limits the ability to understand the methodological implications of choosing one MCDM method over another and hinders the development of consistent evaluation practices.

5.4 Research challenge 4

Include emerging dimensions within the set of indicators for the evaluation of urban mobility, incorporating operational, technical, institutional, behavioral, and spatial-urban dimensions. In addition, the review revealed that most studies restrict their analysis to the traditional sustainability dimensions (economic, environmental, and social); only a few considered the emerging ones, like operational and technical aspects, as well as the use of public space. These emerging dimensions are not yet systematically incorporated into indicator sets, which limits the ability to capture the full range of impacts associated with urban mobility. Furthermore, no studies explicitly incorporate behavioral aspects, even though they are central to understanding mobility patterns.

5.5 Research challenge 5

Develop strategies for the responsible use of open-source traffic microsimulation tools, such as SUMO, to evaluate scenarios and complement existing datasets. At the same time, promote the generation, standardization, and open exchange of robust, up-to-date, and continuous urban mobility databases that can support both the development of indicators and the reliability of models. We highlight the potential role of traffic microsimulation tools, not only for evaluating alternative scenarios, but also for supplementing incomplete datasets needed for indicator development. However, it is important to recognize that initial data is needed to calibrate and validate microsimulation models. Therefore, they cannot completely compensate for the absence of fundamental mobility data, such as traffic counts, segmentation by vehicle type, the way the local street network is organized, or other parameters associated with the car-following models used in traffic microsimulation, which are essential to ensure the reliability of the model. In cities where this reference information is limited, microsimulation should be used with caution and primarily as a tool for exploring scenarios, rather than as a substitute for empirical data. Nevertheless, if the necessary information for traffic microsimulation is available, the model can be used, for example, to obtain indicators associated with pollutant emissions or noise levels, which can be difficult and costly to measure. In this context, strengthening data collection systems becomes a prerequisite, for which it is essential to have robust, continuous, and open-access databases on traffic and urban mobility to support evidence-based planning and enable the calibration of analytical and simulation tools.

5.6 Research challenge 6

Identify the relationship between mobility indicators and the SDGs in order to determine the criticality of each indicator and strengthen the alignment between mobility assessment and global agendas. Also, promote the use of technology for the collection and processing of real-time traffic data, with the aim of developing dynamic indicators that support evidence-based decision-making in smart cities. The review revealed a lack of explicit integration between the indicators used to assess urban mobility and the Sustainable Development Goals (SDGs), as well as with the Smart City framework. Without this link, it is difficult to assess how mobility contributes to global sustainability goals or to identify which indicators are most critical to achieving them. Likewise, it was identified that most studies rely on static indicators or are developed for a specific analysis, even though smart cities increasingly depend on real-time data to support adaptive management. The absence of dynamic indicators limits the ability to monitor system performance and implement timely interventions.

6 Proposed framework

In response to the main challenges identified in the specialized literature on sustainable urban mobility assessment, such as the limited application of these methodologies in medium-sized Latin American cities and the scarce incorporation of emerging dimensions, this study proposes the development of a framework aimed at addressing these gaps. The proposal is based on the participatory and consensus-driven construction of a set of key indicators to evaluate sustainable mobility alternatives in the context of medium-sized Latin American cities, using Bahía Blanca (Argentina) as a case study.

The selected city can be considered medium-sized, as it has 336,500 inhabitants according to the most recent census conducted in 2022 (Instituto Nacional de Estadística y Censos, 2022). Additionally, in 2018, it registered a total vehicle fleet of approximately 172,000 units (Grassi et al., 2021). Bahía Blanca can also be classified as an intermediary urban center, since it functions as a key logistical hub within the country. It hosts a major port and a petrochemical and industrial complex, which generates a significant flow of heavy trucks. However, this freight traffic is routed through bypass corridors, preventing large vehicles from entering residential areas. For this reason, only last-mile delivery operations occurring within the city are considered part of its urban mobility system. In this regard, freight truck movements could be incorporated in future extensions of studies focused on mobility associated with industrial and port activities, which follow a logic that differs substantially from urban mobility. Figure 8 illustrates the spatial distribution of the city, highlighting the downtown area in blue, the port and industrial zones in green, and the bypass routes surrounding the city in red.

Bahía Blanca is also a scientific and academic hub due to the presence of several universities and research institutes. In recent years, the city has experienced unplanned urban sprawl, which has led to an increase in mobility demands, mainly through private vehicles: cars, motorcycles, and pickup trucks. These vehicle types constitute the largest share of the fleet in the city center in 2024, representing 69%, 12%, and 10%, respectively (Grassi and Díaz, 2025a; Grassi and Díaz, 2024a). This situation has resulted in greater congestion, particularly during peak hours, along with rising traffic accidents and higher levels of both air and noise pollution (Grassi and Díaz, 2023). Within this context, Bahía Blanca represents an interesting case study for applying the proposed methodology to

FIGURE 8
Map of the city of Bahía Blanca, Argentina. The bypass corridors surrounding the city are highlighted in red, the port and petrochemical–industrial zone in green, and the downtown area in blue.

select appropriate indicators for a medium-sized Latin American city.

To reach consensus on the most relevant indicators adapted to local characteristics, an initial exploratory stage was conducted using a methodology based on principles of anonymity, independent judgment, and structured consultation. This approach was inspired by the Delphi method, recognized for its ability to systematize expert opinion, which enables progress toward a more comprehensive, reliable, coherent, contextualized, and replicable evaluation of sustainable mobility alternatives in medium-sized Latin American urban environments, settings that remain underexplored and where data availability is often limited. The Delphi method is a structured consultation technique based on expert opinion, characterized by anonymity in responses, controlled feedback, and statistical convergence of views (Linstone and Turoff, 1975). As demonstrated by recent studies such as that by Almashhour et al. (2023), the Delphi method is frequently used as a preprocessing tool within broader decision-making frameworks and MCDM methods. Although the procedure used in this study is not a classical Delphi method, since it does not include iterative rounds, controlled feedback, or statistical convergence, it is similar in its use of the principles of anonymity, independent judgment, and structured consultation, as noted above. This approach is commonly employed in exploratory mobility studies whose objective is to identify and validate relevant indicators rather than to refine expert opinions through multiple rounds (da Silva et al., 2022; Medina et al., 2020).

To ensure a robust and comprehensive assessment of the indicators, the expert panel had to be carefully selected and bring together individuals with complementary expertise relevant to sustainable urban mobility. This included specialized knowledge of the environmental impact of transportation systems and technologies; understanding of how urban mobility works and the dynamics of high-demand transportation users; familiarity with risk management and sustainable development frameworks; perspectives rooted in civil society and active advocacy for mobility; technical knowledge of vehicle technologies, energy efficiency, and transportation infrastructure; knowledge of logistics and industrial mobility flows; and the ability to interpret urban mobility from a multidimensional and strategic perspective. Combining these diverse perspectives helps ensure that the assessment is robust, relevant to the context, and aligned with the practical challenges of urban mobility planning. Building on this rationale, and supported by methodological guidance provided by da Silva et al. (2022), who demonstrated that a panel of seven experts is sufficient to capture a broad and representative range of perspectives in medium-sized Latin American cities, a group of seven local experts was selected for this study. Selection criteria included their technical background, independence of judgment, familiarity with local mobility conditions, and availability to participate.

TABLE 5 Set of twelve indicators selected by at least 50% of the panel of experts.

Selected indicators	Percentage achieved in the survey	Related dimension
Air quality index	100%	Environmental
Quality of public transportation	100%	Social
Accessibility to public transportation	86%	Social
Cost of public transportation fares	71%	Economic
Length of bicycle paths	71%	Spatial-urban
Population density	71%	Spatial-urban
Noise pollution	57%	Environmental
Fossil fuel consumption	57%	Environmental
Vehicle accidents with victims	57%	Social
Public transport operational costs	57%	Economic
Level of service (congestion)	57%	Operational-Technical
Shared mobility	57%	Operational-Technical

Based on the above, the panel of experts was composed as follows: one specialist in the study of electric vehicle motors who also directs a sustainable urban mobility research center at a local university; a researcher in environmental sciences; the president of a non-profit organization focused on active mobility; a person involved in risk management and sustainable development; an expert in public transport routing; a specialist in industry and last-mile logistics; and a professional dedicated to multidimensional urban mobility analysis. Furthermore, the panel was composed of three women and four men to ensure gender balance. Each participant was asked to complete a digital survey presenting the thirty-five indicators listed in Table 3, displayed in random order, and to select the fifteen they considered most representative for evaluating sustainable mobility in our city. Additionally, they were invited to freely specify the criteria guiding their choices. The decision to limit the selection to fifteen indicators sought to maintain methodological balance: on the one hand, ensuring sufficient coverage of the relevant dimensions for a comprehensive assessment; on the other, avoiding excessive complexity and potential inconsistency in future pairwise comparisons, whether using AHP or BWM, where a more concise and strategically selected set of indicators supports more robust and coherent decision-making processes. The work of da Silva et al. (2022) was also considered, as they selected 12 indicators out of a total of 43 in a similar approach.

The process identified a set of twelve indicators as the most relevant and validated by the expert panel (see Table 5). Consensus was operationalized through a simple agreement threshold: indicators selected by at least 57% of experts (four out of seven) were retained. This threshold ensured that each selected indicator had support from a clear majority of the panel. Indicators below this threshold were excluded due to insufficient agreement. No iterative rounds were conducted; therefore, disagreements were not resolved through feedback but through the predefined consensus rule. It should be noted that this stage of the study sought to identify a preliminary subset of indicators validated by local experts, which could be used in future work.

According to expert comments, priority was given to indicators that enable a comprehensive evaluation of urban mobility impacts across various sustainability dimensions (environmental, social, economic, and emerging ones) as well as those directly linked to sustainable mobility modes such as walking, cycling, public transport, and shared vehicles. Moreover, the specialists commented that, while some indicators were selected easily, others required more detailed analysis to ensure strategic relevance, applicability, and measurability. Particular emphasis was placed on balancing society, environment, infrastructure, costs, and mobility, as illustrated in Figure 9, which shows the percentage represented by each dimension (social 29%, environmental 25%, spatial-urban 17%, economic 15%, and operational-technical 14%). This outcome aligns with da Silva et al. (2022), who highlight that most studies tend to use a limited number of indicators and recommend maintaining a balanced proportion of indicators per dimension to ensure analytical coherence. Overall, experts sought to avoid redundancy and favored general indicators that reflect social engagement, system efficiency, and equitable access.

Although the main objective of this framework was to identify, through a participatory process, which indicators experts consider most appropriate for assessing the sustainability of urban mobility in Bahía Blanca, the operational development of these indicators to obtain baseline values of the current situation remains pending. This section presents, in an exclusively methodological manner, how the necessary data could be obtained and how the 12 indicators selected by the panel could be constructed. It is important to note that neither data collection nor an assessment of its feasibility was carried out; these aspects are proposed as future lines of work. Consequently, what is presented here constitutes a preliminary guide to the potential procedures for measuring each indicator, while the evaluation of feasibility, data acquisition, and the effective

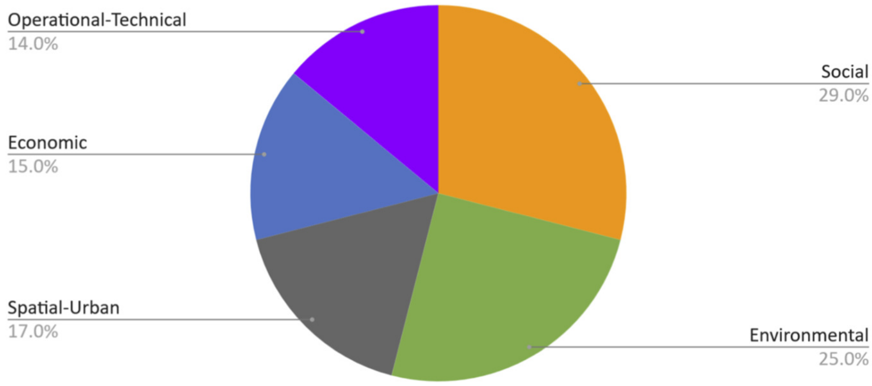

FIGURE 9
Distribution of expert-selected indicators by dimension, based on the number of votes each indicator received.

construction of the indicators are reserved for later stages. In line with the analytical approach adopted in this study, the indicators are conceptually interpreted at a system-wide scale; however, their effective scope will ultimately depend on the local context and the availability of data when assessing their real-world applicability.

For the air quality index, international standards established by the United States Environmental Protection Agency could be used, which require data on concentrations of criteria pollutants (United States Environmental Protection Agency, 2026). Although Bahía Blanca has three continuous air quality monitoring stations, they are located in areas associated with industrial activity and on the urban periphery. For this reason, the available information could be used but should be complemented with additional data, such as validated air-quality modeling results, as applied in previous local studies (Grassi and Díaz, 2024b; Grassi et al., 2022). The quality of public transportation could be measured through surveys of frequent passengers, as well as by considering frequency, punctuality, and the condition of the fleet. It should be noted that Bahía Blanca has a single public transport system composed of 21 urban bus lines. The indicator related to accessibility to public transportation seeks to evaluate whether people can reach a bus stop within a walkable distance. To do so, it would be necessary to map the location of bus stops and calculate average distances or access times. Tools such as UrbanPY, an open-source software developed by the Inter-American Development Bank to measure accessibility to services (Inter-American Development Bank, 2026), would allow this type of analysis. The cost of public transportation, the length of the bicycle path network, population density, public transport operational costs, and vehicle accidents with victims are data already collected by the local municipality or other agencies, and could therefore be requested directly. The consumption of fossil fuels could be obtained from sales records provided by service stations. If such data were not available, an alternative would be to estimate consumption using statistical fuel-use factors or traffic microsimulation models, which allow approximating energy consumption.

Three indicators present greater complexity in terms of data availability: noise pollution, level of service (congestion), and shared mobility. The first two could be measured *in situ*, although this would require specialized equipment and trained personnel, particularly for noise measurement. As an alternative, traffic microsimulation could compensate for the lack of empirical data, since these models generate estimates of noise levels and allow congestion to be evaluated through queue lengths and delay times. These results, combined with direct observations during peak hours, would make it possible to estimate the level of service of the streets, a central indicator in transportation engineering. However, as mentioned previously, the use of microsimulation requires calibration and validation, which in turn demands primary urban mobility data. Therefore, it is worth mentioning that our line of research has urban mobility data (hourly traffic flow and segmentation), as we have been generating it through direct observation of videos from 2020 to the present at strategic points in the city (Grassi and Díaz, 2025b; Grassi and Díaz, 2023; Grassi et al., 2022; Grassi et al., 2021). It is also worth noting that the SUMO software is being implemented incipiently by our research group (Rossit et al., 2025), and that there is strong interest from local authorities in this type of study.

Finally, for the indicator associated with shared mobility, it is necessary to identify which types of shared vehicle systems operate in the city. Many of these services are typically managed through mobile applications, which would allow requesting information from corresponding operators regarding the available fleet and its frequency of use. Carpooling could also be considered within this indicator; however, its measurement is more complex, as many carpooling practices occur without the mediation of digital platforms and are instead based on informal agreements between individuals. In such cases, targeted population surveys would make it possible to estimate how often people share trips with acquaintances or third parties. Another option for estimating this shared-mobility indicator could be to calculate the occupancy factor of private vehicles circulating in the city, which could be obtained through direct observational counts at strategic locations.

In summary, the twelve indicators identified and preliminarily outlined in this study constitute a coherent and context-sensitive basis for evaluating sustainable mobility alternatives in Bahía Blanca. Their methodological adaptability and potential replicability in other medium-sized Latin American cities reinforce the value of this framework as a tool for supporting evidence-based decision-making in urban environments.

7 Final discussions and conclusions

Urban mobility, globally, must evolve towards a people-centered approach, promoting sustainability and adapting to specific local contexts. In this regard, it is important to have tools to assess the sustainability of urban mobility as a whole, as well as to design future scenarios that support evidence-based decision-making. To this end, it is necessary to develop indicators that allow for the evaluation of urban mobility performance, taking into account the local context. Likewise, it is necessary to use MCDM methods that allow for the weighting of indicators and the determination of the best urban mobility alternatives, integrating the points of view of the various stakeholders. This study provides an integrated and up-to-date synthesis of the indicators and multi-criteria decision-making (MCDM) methods used to assess the sustainability of urban mobility. Through a structured review of recent literature, the study identifies only 38 articles that met the inclusion criteria, which required a holistic perspective on urban mobility. This outcome reflects the scarcity of studies that consider urban mobility as an integrated system, but it also represents a limitation of the study itself, as the selection criteria applied were strict.

It is noted that most research and tools are applied in large cities in Europe, America, and Asia, leaving a significant gap in Latin America, especially outside Brazil, where there is a lack of data. In this context, this study initially identified the 35 most commonly used indicators in the literature for assessing the sustainability of urban mobility, considering all its constituent aspects. On the other hand, in addition to the traditional dimensions of sustainability (social, environmental, and economic), other relevant dimensions were identified, which complement the previous ones, such as operational and technical dimensions and the use of public space.

Regarding the MCDM methods, the review shows that there is no single method that is universally optimal for assessing the sustainability of urban mobility. The suitability of each approach depends on factors such as the complexity of the transport system, the quality and completeness of available data, the number of indicators and alternatives considered, and the specific decision-making context. While AHP and TOPSIS are the most frequently used, several studies combine or hybridize techniques to address the multifaceted nature of urban mobility challenges. Importantly, all MCDM methods identified in the review proved useful in their respective applications, regardless of the specific method chosen. In contexts where data are incomplete or noisy, a common situation in developing-country cities, outranking methods or approaches incorporating fuzzy logic or grey systems theory may offer greater robustness than purely compensatory methods. Overall, MCDM tools play a central role in supporting sustainable urban mobility planning, enabling stakeholders to set priorities, monitor progress, and make informed, evidence-based decisions.

Based on the research gaps identified in this review, such as the limited application of these methodologies in Latin American cities, the scarce consideration of emerging sustainability dimensions, and the need for evidence-based decision-making, this study implemented an expert consultation process to determine which indicators are best suited to assess the sustainability of mobility in a medium-sized Latin American city such as Bahía Blanca (Argentina). This participatory approach made it possible to refine the initial set of indicators and arrive at a final group of twelve. The experts prioritized indicators that enable a comprehensive evaluation of the impacts of urban mobility on sustainability and that are directly linked to sustainable mobility modes, including cycling, public transportation, and shared vehicles.

At this point, it should be noted that although the size of the expert panel is consistent with similar studies conducted in medium-sized Latin American cities, it may limit the generalizability of the selected indicators. Likewise, it should be considered that the proposed indicators were neither implemented nor measured, as this study focused on conceptual identification rather than empirical evaluation. These limitations highlight the need for future research, which should focus on operationalizing the proposed indicators, assessing data availability, and testing their performance in real decision-making scenarios. Strengthening local data systems, integrating traffic microsimulation tools, and expanding stakeholder participation will be essential steps toward more robust and actionable sustainability assessments. Future studies should continue addressing the challenges identified, particularly those related to emerging sustainability dimensions and the limited application of these methodologies in Latin American contexts. Furthermore, the authors will continue developing research related to the evaluation of sustainable urban mobility, with the aim of contributing to evidence-informed decision-making. Finally, this work seeks to lay the groundwork for applying these approaches in medium-sized Latin American cities, helping to reduce existing research gaps and strengthen strategic decision-making in the pursuit of more sustainable, equitable, and resilient urban mobility systems.

Author contributions

YG: Formal Analysis, Conceptualization, Data curation, Writing – original draft, Investigation, Writing – review and editing. MD: Project administration, Funding acquisition, Formal Analysis, Supervision, Writing – review and editing, Investigation. DR: Formal Analysis, Conceptualization, Project administration, Supervision, Funding acquisition, Investigation, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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