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The Role of Smart Mobility Stations in Sustainable Urban Mobility

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ABSTRACT

In the first decades of the 21st century, both academic interest and real-world efforts related to urban mobility and public transportation two foundational aspects of the sustainability agenda have notably increased. The swift evolution of technology is gradually transforming traditional urban transportation systems, paving the way for innovative solutions. Among these innovations, the proliferation of electric vehicles and the integration of digital technologies have played a pivotal role in reshaping public transit dynamics. A key development in this context is the advent of Smart Mobility Stations (SMS), which aim to revolutionize urban transport by offering flexible, inclusive, and interconnected mobility options. These platforms are influencing various facets of urban mobility, including travel behavior, multimodal transport systems, digital connectivity, environmental sustainability, and shared resource use. Distinguished by their decentralized structure and high adaptability, smart mobility stations are emerging as viable alternatives to conventional transport stations. Commonly discussed in academic literature under terms like e-mobility, smart mobility, or shared mobility, these innovations are vital for promoting sustainable transport and fostering smart urban development. This research examines the current state of smart mobility stations deployment, the challenges they face, their influence on city life, and the novel frameworks they introduce, alongside their broader societal implications. In response to the global climate crisis and the intensifying urbanization trend, sustainable transportation solutions have gained prominence. This study assesses how smart mobility stations are integrated into existing transit networks, evaluates their operational efficiency, and investigates their effects on user behavior. Through a review of academic literature and analysis of case studies, the paper highlights the environmental, economic, and social benefits of smart mobility stations, and offers strategic policy recommendations concerning digital infrastructure, governance mechanisms, and urban planning.

1. Introduction

The ongoing surge in global urbanization is exerting considerable strain on transportation systems and compelling cities to pursue environmentally, socially, and economically sustainable solutions [1]. In this evolving landscape, traditional transport systems reliant on private car use are increasingly scrutinized due to their contribution to traffic congestion, air pollution, and greenhouse gas emissions [2,3]. To address these mounting concerns, sustainable micromobility options such as

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electric scooters, bicycles, and cars are gaining traction. In particular, shared e-mobility services are emerging as eco-friendly and user-centric alternatives, especially for short-distance urban trips [4].

Mounting challenges such as urban expansion and climate change are accelerating the shift toward more sustainable transport options and away from car-dependency [5]. smart mobility stations play a vital role in this transformation by enhancing last-mile mobility and offering significant potential for emission reduction, especially when paired with renewable energy systems like solar panels and energy storage solutions [6]. Innovative shared mobility solutions including public transit, bicycles, e-mopeds, and scooters are now considered essential elements in shaping future mobility. A key aspect of this shift lies in the seamless integration of these modes, which is vital for enabling efficient intermodal travel [7-8]. As such, identifying the spatial factors influencing the optimal distribution of mobility stations is crucial for both transport planners and policy developers. Nevertheless, existing research on the spatial and socio-environmental determinants of station efficiency and placement remains insufficient [9]. Facilitating a transition to more sustainable transportation systems remains a core challenge in urban planning, requiring a fundamental rethinking of conventional mobility policies and planning practices [10]. As a relatively new urban planning tool, mobility stations aim to interconnect various transportation modes such as bicycles, e-scooters, car-sharing, and public transit thereby reducing car reliance in urban areas [11-12].

Driven by an increasing need for sustainability, urban mobility systems are undergoing rapid transformation. Smart transportation technologies are now considered foundational in building more livable cities [13]. Alongside developments such as autonomous vehicles, electric transport technologies, and hyperloop systems, smart mobility stations (SMS) offer a flexible and low-emission alternative to car use, playing an important role in advancing multimodal and sustainable urban mobility [6-14].

In this context, smart mobility stations (SMS) have emerged as key infrastructural elements of the next-generation urban transport network. By co-locating multiple electric mobility options such as e-bikes, e-scooters, and electric cars these stations make shared mobility services more accessible to users. Their goal is to minimize reliance on private vehicles while fostering a more integrated and sustainable urban transport ecosystem [14-15]. Furthermore, smart mobility stations serve as physical anchors for the Mobility-as-a-Service (MaaS) framework, supporting its expansion into the urban fabric [16]. In doing so, they act as innovative infrastructures that encourage multimodal travel behaviors and sustainable mobility choices. Functioning as both spatial and operational nodes, they enhance access to electric transport while aligning with broader ecological and societal objectives [16-17].

Recent literature underscores the significance of spatial planning, stakeholder cooperation, and data infrastructure in the successful deployment of smart mobility stations. Partnerships among public transit authorities, mobility service providers, and property stakeholders have revealed systemic gaps in infrastructure development and service integration [18]. Additionally, understanding how various demographic groups adopt these technologies based on differing travel patterns is critical for formulating effective design strategies and public policies [14].

Shared mobility models, such as car-sharing, ride-sharing, and public bike systems, are transforming how individuals engage with transportation infrastructure. When combined with Mobility-as-a-Service (MaaS) platforms, these systems can help reduce reliance on private car ownership and promote more personalized, integrated travel planning [13]. However, challenges such as inadequate charging and parking infrastructure, limited digital integration, and underdeveloped data ecosystems still hinder the scalability of these solutions [6-19]. Although these innovations hold great potential, the successful integration and operation of smart mobility stations face various obstacles. These include a lack of proper integration with public transport, fragmented digital services, uncertainties in energy supply, and the absence of user-focused design strategies [3-20]. Furthermore, decision-making and governance mechanisms for infrastructure development at the intersection of energy and transportation often lack adequate coordination [21]. Despite the growing adoption of these systems, there are still considerable gaps in the literature concerning critical issues like the optimal placement and sizing of smart mobility stations, user behavior, and demand patterns [3-17-22]. For example, the integration of micromobility infrastructure with existing public transport networks has not yet reached the desired level. Moreover, uncertainties in modeling factors such as energy consumption, user preferences, and geographical coverage make planning and scaling these systems more challenging [3-23]. Additionally, there is a strategic gap in terms of governance structures, decision-making processes, and collaboration among relevant stakeholders [21].

The success of smart mobility stations should be assessed not just from a technical standpoint, but also in terms of social acceptance, user preferences, and spatial equity. Research in various cities indicates that attitudes towards shared mobility differ widely depending on factors such as age, education, vehicle ownership, and awareness of sustainability [22-24]. As a result, effective station planning must take into account not only the physical infrastructure but also the design of services that prioritize the needs and preferences of users [25].

In recent years, the smart city model has become central to urban development, with sustainability at its core [26]. Micromobility services support first- and last-mile travel with environmental benefits, but their spatial usage within mobility stations remains insufficiently studied [27]. Mobility stations, centralized locations offering access to shared bikes, scooters, cars, and micro-transit, extend public transport networks, facilitate transfers between modes, and encourage alternatives to single-occupancy vehicles. Designed to prioritize user needs, these stations focus on accessibility and safety, especially for vulnerable groups such as women, disabled individuals, and BIPOC populations [28].

Rural public transport systems face accessibility issues and long wait times, which can be improved by demand-responsive mobility options. Mobility stations can enhance public transport by providing faster intermodal connections [29]. Multimodal transport systems are essential for sustainable urban mobility. Mobility stations, by supporting mode switching, facilitate multi-level governance and eco-friendly transportation. However, research primarily focuses on design, user needs, and environmental impact, with limited practical application [30].

The goal of mobility stations is to reduce reliance on single-occupancy cars and promote sustainable transport. These stations, often in dense urban areas, enhance both transportation options and community vibrancy. E-mobility stations, providing electric vehicles, bikes, and charging stations, emphasize clean transport [31]. Reducing private car ownership is vital for decarbonization but is not yet fully embraced in transport policy. More efficient use of fewer vehicles offers a socially progressive approach to carbon reduction [32]. Shared mobility services like car-sharing, bike-sharing, and scooter-sharing optimize resources and are often integrated into mobility stations for on-demand access [33]. However, rapid growth of shared mobility raises concerns, such as overcrowding and safety issues, which mobility stations can help address [34]. The future of mobility presents challenges, such as redesigning transport systems, creating new infrastructure, and changing bureaucratic models to deliver innovative technologies [35].

Saravanan [36] examines the impact of mobility stations on transportation networks and the appropriate typology for specific areas. The research investigates how mobility stations affect transportation usage in settlement areas. "Mobihub," a term for mobility stations, refers to a physical, recognizable location that offers various shared transport modes and facilities, attracting passengers and providing benefits [37]. As multimodal services increase, municipal investment in mobility stations becomes crucial to improving access to transportation [38]. The sector should shift from focusing on vehicle sales to miles traveled, designing vehicles around human needs with insights from data, especially in the context of electric, autonomous, and shared transport [35].

The purpose of this study is to thoroughly explore the role of smart mobility stations in promoting sustainable urban transportation within the rapidly evolving shared e-mobility landscape, and to identify planning, location selection, and management strategies that can improve the effectiveness of these stations. By focusing on multimodal integration frameworks, data analytics techniques, and contemporary methods for modeling user behaviors found in the literature, the aim is to offer a comprehensive approach to making smart mobility stations more inclusive, accessible, and efficient. Through enhancing our understanding of the strategic and operational aspects of smart mobility stations, we seek to contribute to more sustainable urban mobility transitions and assist policymakers and urban planners in developing more inclusive, energy-efficient, user-focused, future-proof, and resilient urban mobility systems.

2. Literature Review and Conceptual Background

Shared electric mobility has become central to sustainable transportation solutions in recent years. Smart mobility stations, as physical manifestations of this transformation, are multimodal centers where users can access e-bikes, e-scooters, e-mopeds, and electric vehicles, often integrated with public transportation stops [17]. Smart mobility stations (SMS) are facilities that combine various shared e-mobility options, such as e-bikes, e-scooters, and electric vehicles, into a single location. These stations promote integration within transportation networks and encourage multimodal travel behaviors [17]. They also provide several benefits, including integration with public transportation, a reduction in carbon emissions, and better use of public spaces [16-39]. The effective operation of smart mobility stations relies on factors like site selection, charging infrastructure, and usage patterns. Many studies have demonstrated that tools such as GIS-based analyses [40], data envelopment analyses [2], and optimization algorithms (MILP, VNS) are valuable in making location decisions for smart mobility stations [16]. In addition to affecting transportation infrastructure, smart mobility stations also have a direct impact on energy systems. A study in Milan explored the effects of both fast and slow charging stations on the electrical grid, identifying potential disruptions in power quality [41]. This issue is crucial for ensuring energy supply security and system stability.

The successful deployment of shared mobility stations depends heavily on choosing optimal locations. Key factors for location selection identified in studies include proximity to public transport, availability of pedestrian and bicycle infrastructure, environmental sustainability, population density, user demographics, and the spatial potential of the area [19-42]. Arnold *et al.,* [1] stress the significance of involving stakeholders, effective branding, and ensuring integration with public transport in both the design and site selection of smart mobility stations. Furthermore, Coenegrachts *et al.,* [20] developed five distinct business model frameworks that serve as valuable tools for influencing user behavior. Ultimately, this study reviews research aimed at advancing sustainable urban transport solutions and the integration of shared mobility systems, highlighting essential findings in this field. These studies can help enhance the role of mobility stations in cities and contribute to the long-term sustainability of transportation systems [43-44].

In the literature, smart mobility stations are viewed as an important tool for decarbonizing transportation systems, enhancing accessibility, reducing dependence on private vehicles, and encouraging multimodal behaviors [2-45].

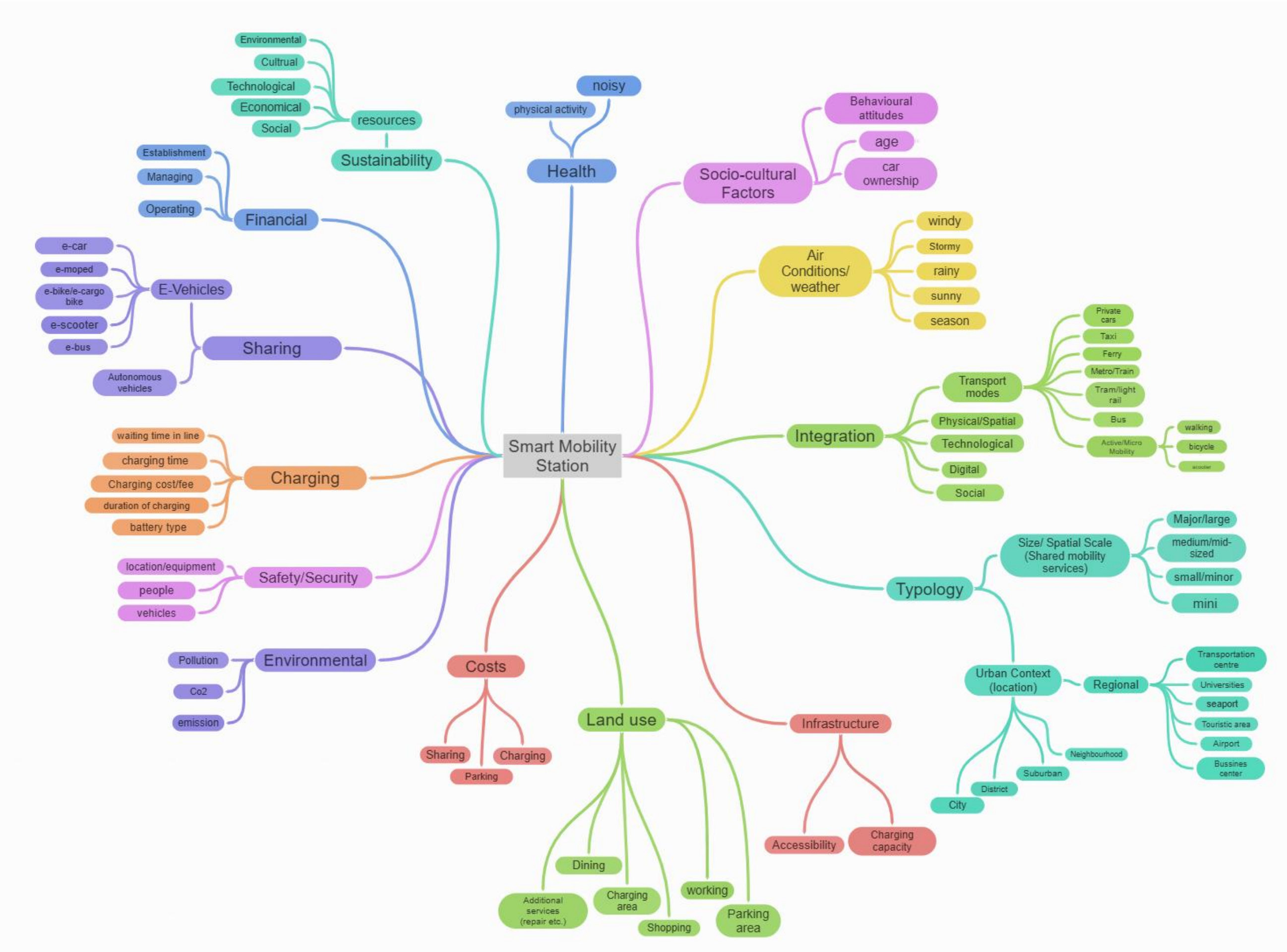

Fig. 1. Mind map; conceptual map of station and associated concepts

Figure 1 presents a mind map illustrating the concept of station along with its related terms, which are discussed in this section. The most essential concepts are briefly outlined below.

2.1. Terminological Framework and Development of Smart Mobility Stations

In the urban mobility literature, several terms are used to describe locations where multiple mobility services are integrated, including mobility hubs, mobility centers, e-hubs, and smart mobility stations. Although these terms often refer to similar concepts, they may differ slightly depending on the planning context, policy framework, and geographical application. Generally, these concepts describe physical or digital platforms that facilitate the integration of public transport, shared mobility services, micromobility options, and other sustainable transportation solutions. In order to maintain terminological clarity and consistency throughout this study, the term Smart Mobility Stations (SMS) is adopted as the primary concept. Accordingly, other related terms appearing in the literature are considered conceptually aligned with this framework but are collectively referred to as

Smart Mobility Stations (SMS) within the scope of this research. The terminological framework of Smart Mobility Station concepts is presented in Table 1.

To analyze the built and social environment factors of mobility centers, it is first necessary to define the term "mobility center" used in this article. Additionally, various terms such as "Smart Centers," "Smart Mobility Centers," "Mobility Stations," or "Public Transport Stations" are commonly used by mobility planners. There is no universal definition for the physical structure of mobility centers. Instead, mobility centers are defined through their contributions to the current and future sustainable transportation transition, with individual adjustments made according to the specific needs of different locations [9].

Table 1

The Terminological comparison of smart mobility station concepts

Term	General Definition in Literature	Main Focus	Typical Characteristics
Smart Mobility Stations (SMS)	Integrated mobility locations combining digital technologies and multiple transport services	Smart and integrated mobility systems	Integration of public transport, shared mobility, micromobility, digital platforms, and smart infrastructure
Mobility Hubs	Physical locations where different transport modes connect and allow seamless modal transfer	Multimodal integration	Co-location of transport modes, improved accessibility, last-mile connectivity
Mobility Centers	Organized mobility nodes providing mobility services and traveler information	Service-oriented mobility coordination	Information services, ticketing integration, coordination of transport services
E-hubs	Electrified or technology-oriented mobility hubs emphasizing sustainable mobility solutions	Electrification and sustainable transport	Electric vehicles, charging infrastructure, micromobility services

However, as commonly defined in the literature, all mobility centers create opportunities for multimodal travel by providing strong connections between different modes of transportation [46-47-48]. They can be seen as an "interface between the transportation network and the spatial structure of an area [optimally organized and designed]" [48] and are complemented by additional services to attract and benefit the traveler, along with various facilities and information features [9].

The transportation challenges faced by modern cities, combined with technological advancements and sustainability requirements, have led to the search for new solutions in urban mobility. In this context, the terms "station" and "mobility," influenced by digitalization, represent innovative systems that integrate both physical and digital transportation infrastructures. A station can be defined as a multifunctional center that integrates different types of transportation through a digital platform. This system enables the management of various forms of transportation, such as public transport, car-sharing, micromobility (e.g., bikes and scooters), electric vehicles, and pedestrian access, from a single location [49].

Mobility, on the other hand, refers not only to physical movement but also to the realization of this movement in a data-driven, environmentally friendly, accessible, and user-centered manner [50].

Farahani *et al.,* [51] note that the hub location problem has evolved from traditional facility location problems to be applied to transportation. In this context, smart mobility stations are not only about the physical provision of vehicles but also include digital reservation systems, charging infrastructure, and multifunctional access points supported by user-specific incentives [52].

Therefore, one of the key aspects of defining mobility centers is their proximity to large public transport stations or corridors, as these stations serve as high-traffic transit points, forming a critical element for mobility. Thus, the proximity or accessibility of public transportation modes can be considered a universal factor in defining and locating mobility centers. The features and location of a mobility center are based on the social, economic, and mobility-related conditions of the area. Generally, the placement of mobility centers must be done according to the needs of the area in question. There are no general standards or regulations regarding the elements that mobility centers should provide; rather, customized solutions are developed for each situation [46-47-48-53-54].

2.2. Smart Mobility Systems: Infrastructure, Technology, Integration, and Mobility as a Service (MaaS)

The MILP-based models and VNS algorithms proposed by Sadati [16] aim to optimize the placement of smart mobility stations and the efficient distribution of charging infrastructure. Additionally, these stations, equipped with ICT (Information and Communication Technology) solutions, also serve as digital bridges necessary for users' multimodal travel [21].

The Mobility-as-a-Service (MaaS) approach enables the integration of different transportation modes in a digital environment, allowing users to plan, book, and pay for their trips through a single application. station structures act as the physical and digital convergence points of MaaS systems. In this context, smart mobility stations support the intermodal transformation of transportation while prioritizing the user experience [55].

2.3. User Behavior and Demand Factors

Bösehans *et al.*, [14-56] emphasize that demographic and psychological factors play a decisive role in the user acceptance of smart mobility stations. Individuals who are highly educated, younger, and have a high level of environmental concern are more likely to adopt these systems. Liao and Correia [57] demonstrate that variables such as travel time, cost, and ease of access significantly influence station preferences.

2.4. Sustainability Perspective and Environmental Impact

Station systems offer an environmentally friendly structure, particularly in terms of reducing carbon emissions and promoting the widespread adoption of transportation solutions powered by renewable energy. Electric vehicle charging stations, bicycle parking facilities, and infrastructure integrated with green energy sources make smart mobility stations a fundamental component of sustainable transportation [58].

The environmental benefits of station systems are directly associated with reducing CO_2 emissions. A study conducted by Hosseini and Caulfield [59] in Dublin demonstrated that smart mobility stations have the potential to replace 20% of private vehicle trips, resulting in a significant reduction in emissions. However, research also indicates that smart mobility stations should be supported not only by public transport integration but also through city planning, user education, and behavior change strategies [15-60]. Mobility stations are seen as an effective tool for reducing CO_2 emissions, improving air quality, and decreasing dependence on private vehicles. For example, according to CROW [61] data:

- One shared vehicle can replace 9–13 private cars,
- It can free up 5 parking spaces,
- It can prevent 175–265 kg of CO_2 emissions per vehicle annually.

Similarly, a study by Ku *et al.,* [62] on mobility stations designed for Seoul showed a 2% reduction in carbon emissions by reducing vehicle kilometers.

2.5. Data-Driven Mobility, Optimization and Mobility Systems in Smart Cities

Station systems have the capacity to collect, analyze, and present real-time data. This data plays a crucial role in optimizing urban transportation networks, reducing traffic congestion, and helping users select the most efficient routes. As a result, cities can achieve less time loss, lower energy consumption, and a more efficient transportation system [63]. The data includes various information such as user densities, traffic conditions, and route alternatives. With real-time data, both users can enjoy an optimal transportation experience, and city administrations can streamline transportation planning.

One of the primary goals of smart cities is to establish transportation systems that are both people- and environment-oriented. E-hub and mobility systems directly contribute to this goal. Through digitalized transportation infrastructure, traffic congestion is reduced, resource usage is optimized, and environmental impacts are minimized. At the same time, these systems enhance social inclusivity by making transportation accessible to individuals of all ages and abilities [50].

2.6.Decision-Making and Policy Dimension

The "4P" model proposed by Arnold *et al.,* [64] Purpose, Process, Place, and Performance serves as a valuable framework for decision-makers in the development of smart mobility stations. In this context, public-private partnerships, urban integration, and participatory planning play a crucial role in the successful implementation of smart mobility stations [12-20].

Overall, the reviewed studies demonstrate a broad consensus regarding the importance of integrated mobility infrastructures in supporting sustainable urban transportation systems. While many scholars emphasize the role of multimodal integration in improving accessibility and reducing car dependency, differences emerge in the proposed implementation strategies and governance frameworks. Taken together, these studies highlight several recurring themes, including multimodal connectivity, technological integration, and user-oriented mobility services. Despite the growing body of research on mobility hubs and integrated mobility systems, significant gaps remain regarding their spatial typologies and operational frameworks. Building on these perspectives, the present study aims to contribute to the literature by providing a more systematic analysis of the typological and conceptual characteristics of smart mobility stations.

3. Methodology and Application Areas

This study was conducted using a qualitative literature synthesis method. The literature review focused on more than 100 academic sources, primarily published after 2016, that center on shared e-mobility systems, smart mobility stations, and urban mobility. The statement referring to “100+ academic sources” includes both peer-reviewed academic publications and additional relevant grey literature (e.g., policy reports, institutional documents, and mobility strategy papers) that informed the conceptual development of the study. Tables 2, 3 and 4 present a structured subset of 99 peer-reviewed academic publications that were systematically analysed. The remaining sources were used to support contextual understanding and theoretical framing but were not included in the tabulated dataset to ensure methodological clarity and consistency in the presentation of empirical classifications. The reviewed studies include case analyses, optimization modeling, user surveys, and policy evaluations.

Statistical data and analyses related to the literature review are presented in Table 2, Table 3, Table 4, Figure 2, Figure 3, and Figure 4. Table 2 and Figure 2 provide information about the types of publications; Table 3 and Figure 3 present the years in which the publications were made; and Table 4 and Figure 4 show the countries where the publications were conducted.

As seen in Table 2 and Figure 2, journal articles rank first among publication types with 65.7%, while report-project type publications also hold a significant share. It is also noteworthy that 13,1% of the publications related to station have been handled and studied as thesis topics.

Table 2
The count and rate of station publication types

Publication type	Count	%
Article	65	65,7%
Report-projects	13	13,1%
Conference Paper	10	10,1%
Master thesis	8	8,1%
Doctoral thesis	2	2,0%
Bsc thesis	1	1,1%
Total	99	100,0%

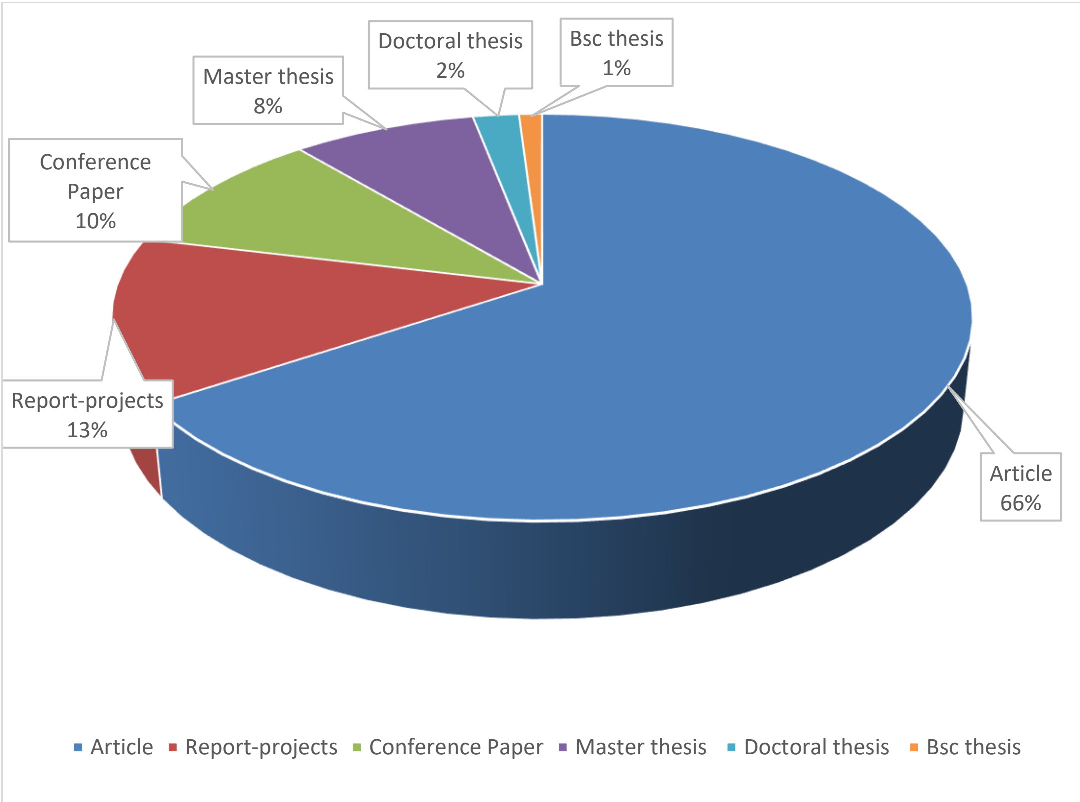

Fig. 2. The rate of station publication types

As seen in Table 3 and Figure 3, the number of publications has entered an upward trend since 2017, with a particularly notable increase observed between the years 2022 and 2025. The number of publications during this period amounts to 73, representing 73.7% of the total publications.

Table 3
The number of station publication per year

Publication Year	Number of Publication	%
2013	1	1,0%
2014	0	0,0%
2015	0	0,0%
2016	1	1,0%
2017	3	3,0%
2018	4	4,0%
2019	2	2,0%
2020	8	8,1%
2021	7	7,1%
2022	21	21,2%
2023	18	18,2%
2024	19	19,2%
2025	15	15,2%
Total	**99**	**100,0%**

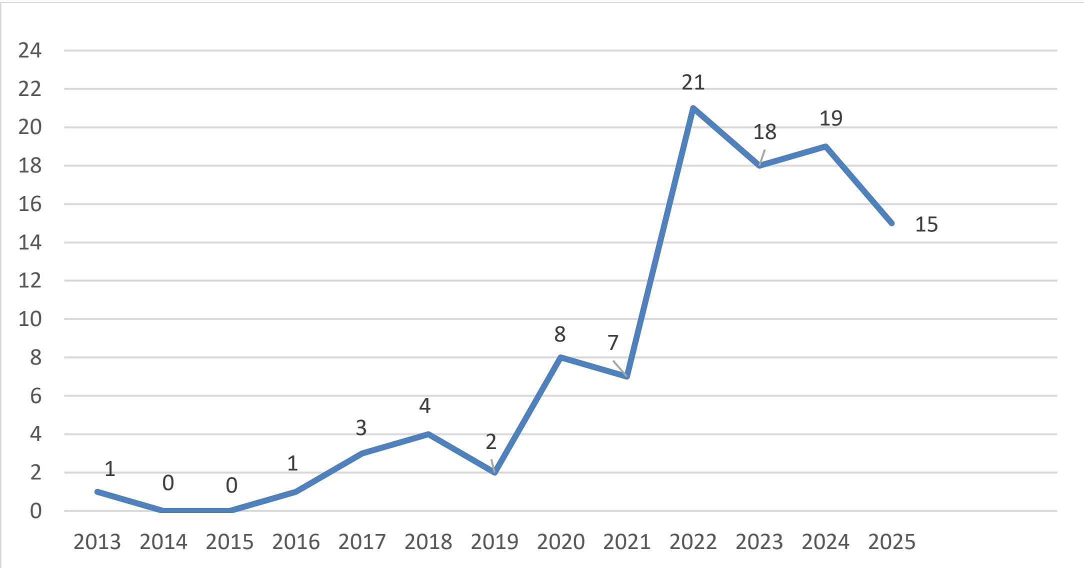

Fig. 3. The number of station publication per year

As seen in Table 4 and Figure 4, the Netherlands ranks first in the number of publications by country, with a striking 29.3%. This statistic confirms the Netherlands' leading position globally in both sustainable practices and public transportation. Another notable point is the dominance of European countries in station-related publications, with the United States standing out as an exception. Among the data covering a total of 23 countries, it is particularly noteworthy that 84.8% of the publications were produced by only 12 countries 9 of which are European.

Table 4
The number and proportion of station publications by Country

No	Publication country	Count	%	Count	%
1	the Netherland	29	29,3%		
2	UK	10	10,1%	39	39,4%
3	Ireland	8	8,1%		
4	USA	7	7,1%		
5	Italy	5	5,1%	20	20,2%
6	Germany	4	4,0%		
7	Belgium	4	4,0%		
8	Canada	4	4,0%		
9	France	4	4,0%		
10	Spain	3	3,0%		
11	Sweden	3	3,0%		
12	Brazil	3	3,0%	25	25,3%
13	Croatia	2	2,0%		
14	Greece	2	2,0%		
15	Poland	2	2,0%		
16	China	2	2,0%		
17	Turkey	1	1,0%		
18	Austria	1	1,0%		
19	Finland	1	1,0%		
20	Switzerland	1	1,0%		
21	Hungary	1	1,0%		
22	Iran	1	1,0%		
23	S. Korea	1	1,0%		
	Total	99	100,0%	84	84,8%

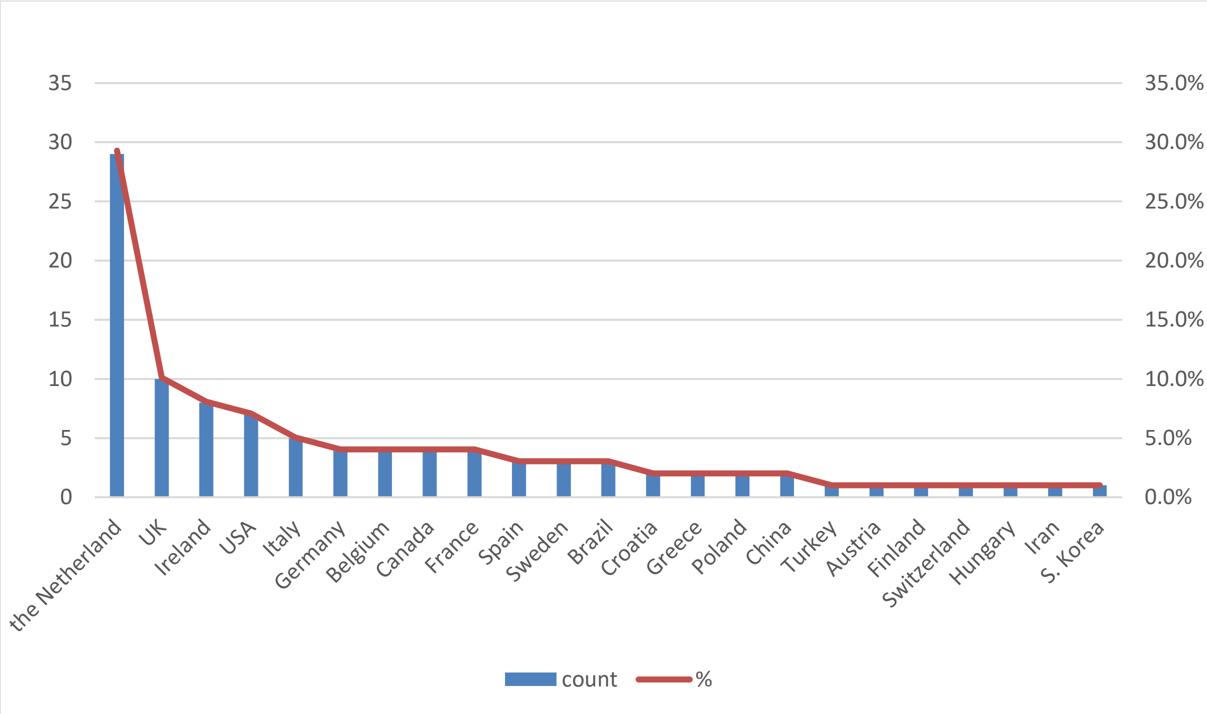

Fig. 4. The number and proportion of station publications by Country

3.1. Data Sources

The sources reviewed were compiled from leading academic databases such as Google Scholar, Springer, Elsevier, Web of Science, Scopus, and Taylor & Francis. In addition, field-based research from Horizon Europe, H2020 projects, and initiatives implemented in various European cities were also included. This approach enabled a comprehensive evaluation of both the theoretical framework and practical applications.

3.2. Application Areas: Europe-Focused Spread

Electric mobility stations (smart mobility stations) are implemented as multimodal transportation solutions shaped by the unique needs and contexts of different cities. These stations not only contribute to sustainability goals but also play a key role in restructuring urban mobility infrastructure and transforming individual travel behaviors.

Applications across Europe showcase some of the most advanced examples of smart mobility stations. In cities like Amsterdam and Rotterdam (the Netherlands) and Aachen (Germany), smart mobility stations are integrated with shared e-car, e-bike, and e-moped systems, establishing physical connections with public transport stops, cycling paths, and pedestrian-priority zones [40-65]. These stations are particularly designed to address first/last-mile challenges.

A case study conducted in Inverness, Scotland, used data from the 2021–2022 period and applied a two-stage Data Envelopment Analysis (DEA) to evaluate station performance, revealing that population density and weather conditions significantly affect demand [39].

In Dublin, Ireland, analyses highlighted the impact of infrastructure quality and public transport integration on station efficiency. The findings indicated that strategic site selection significantly boosts user engagement [59].

The station model, conceptually developed as part of the ROBUST (Electric shaRed mOBility stations Trial) project, led by the Trinity Centre for Transport Research and Innovation for People (TRIP) at Trinity College Dublin, aims to conduct a long-term pilot of electric shared mobility stations in four urban areas in Ireland: Dublin, Waterford, Galway, and Sligo. These stations will include electric vehicle charging stations, electric cars, e-bikes, and e-cargo bikes provided by stakeholders, thereby complementing or replacing existing micromobility options. The two-year pilot will assess the potential for sustainable changes in travel behavior while generating a comprehensive understanding of mobility hub operations and building institutional capacity for nationwide implementation. The project will follow an experimental approach, analyzing participants' travel patterns before the trial, their interaction with the mobility options during the trial, and the persistence of modal shifts afterward. By implementing the stations across four regions that reflect different urban scales in Ireland, the project will evaluate the effectiveness of these mobility solutions in varied contexts [66].

Mobility station applications developed within the scope of sustainable urban transport policies in Europe aim to reduce private car dependency and minimize environmental impacts by integrating multimodal transport systems. In France, Hubs de Mobilité located around train stations in Paris integrate shared vehicles, micromobility solutions, and public transportation [67]. The Netherlands, particularly Amsterdam and Utrecht, has introduced mobiliteitshubs supported by OV-fiets bicycle rentals, Park & Ride systems, and e-scooters, usually positioned near railway stations [68]. In Switzerland, the SwissPass system enables seamless access to all transportation modes via a single digital card under the MaaS (Mobility as a Service) concept [69]. In Scandinavian countries such as Denmark and Sweden, mobility hubs are integrated with bicycle infrastructure, electric vehicle stations, and digital travel planning tools. The common objective of these initiatives is to reduce CO_2 emissions, alleviate urban congestion, and facilitate sustainable and fast multimodal access for users [70]. In Germany, cities like Berlin have implemented Mobilitätsstationen, combining bicycle and scooter sharing, electric vehicle charging infrastructure, and public transit through a single digital platform. Jelbi stations facilitate seamless multimodal transport by integrating shared mobility services such as cars, bicycles, e-scooters, and taxis into Berlin's S-Bahn and U-Bahn infrastructure. These hubs enable users to rent, return, and charge vehicles, all in one location. Through the Jelbi app, individuals can select and reserve vehicles tailored to their mobility needs, enabling efficient door-to-door journeys. The long-term objective is to expand Jelbi stations citywide, enhancing first- and last-mile connectivity across urban and suburban areas [71]. Figure 5 presents three distinct models of Jelbi mobility station implementation currently in use across different urban contexts in Germany.

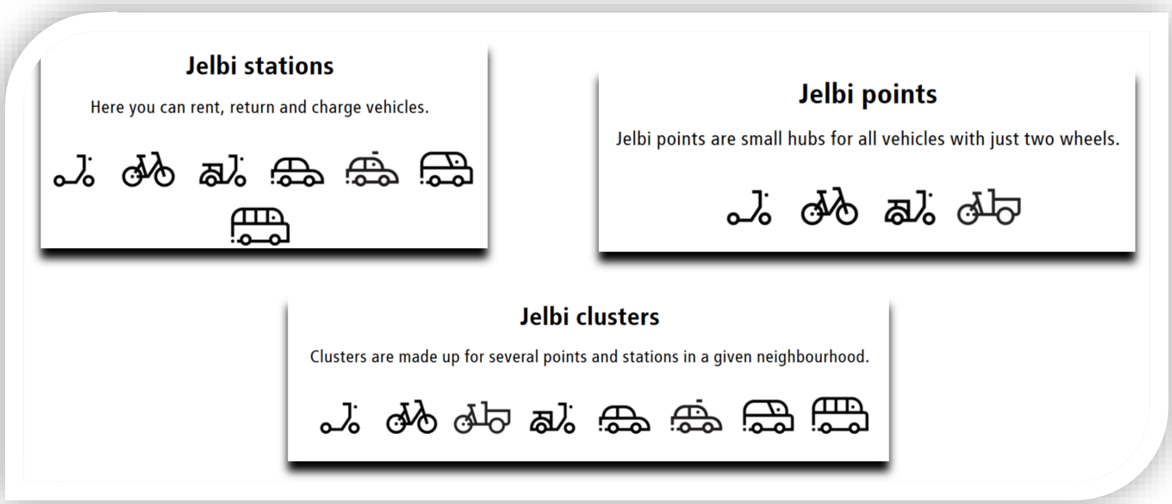

Fig. 5. The approach types to the implementation of Jelbi mobility stations in Germany

These structures differ in terms of scale, service diversity, and level of mobility integration. Jelbi Points represent small-scale mobility locations mainly designed for the parking and organization of micromobility vehicles. Jelbi Stations function as medium-scale multimodal hubs where multiple mobility services are integrated, enabling users to transfer between different transport modes. Jelbi Clusters refer to larger spatial systems consisting of multiple Jelbi Stations and Points within a defined area, forming an integrated neighborhood-level mobility network. The main differences between these three Jelbi models are presented in Table 5.

Table 5
The comparison of Jelbi mobility models

Feature	Jelbi Points	Jelbi Stations	Jelbi Clusters
Scale	Small	Medium	Large
Planning scale	Street / micro scale	Transport node / local scale	Neighborhood / regional scale
Physical infrastructure	Simple markings or small parking area	Organized mobility station	Network formed by several stations
Service diversity	Usually single mobility service	Multiple mobility services	Network of several stations and services
Main purpose	Micromobility parking point	Multimodal mobility transfer hub	Regional mobility network

3.3. Limitations

The main limitation of this study is that it does not produce primary data directly and relies solely on existing academic sources. However, this shortcoming has been addressed through a comprehensive synthesis that brings together findings from various disciplines.

4. Result and Discussion

It is clear that station systems have become one of the cornerstones of sustainable urban mobility. These systems have been proven in numerous case studies to contribute to multiple goals such as reducing car dependency, lowering carbon emissions, and promoting multimodal transportation [72-73]. However, this success varies depending on the implementation context, local policy framework, and user profile.

Studies show that station systems are not only a transportation infrastructure but also a tool for social, environmental, and economic transformation. User profiles, infrastructure quality, digital platform integration, and governance approaches determine the success of these stations. On the other hand, the long-term success of smart mobility stations can only be achieved through designs and implementations tailored to local contexts [25].

4.1. Current Challenges

Although station systems hold great potential in terms of environmental and urban planning, they face certain challenges such as infrastructure deficiencies, user habits, regulatory mismatches, and investment costs. Furthermore, to enhance the effectiveness of these systems, the development of user-friendly digital platforms, the expansion of charging infrastructure, and the strengthening of public-private partnerships are essential [74-75].

Shared e-mobility systems still have some design and operational shortcomings. The lack of integration, unpredictability of energy consumption, and insufficient user-centric perspective are the key factors limiting the development of this area [45]. Additionally, inadequate governance processes [21] and regulatory barriers also make adaptation difficult [20].

4.2. Gaps and Inconsistencies in the Literature

The potential of station systems in developing countries. Additionally, data on user behavior typically relies on short-term observations and does not provide sufficient insights into long-term behavior changes [76]. Another limitation is the ongoing debate surrounding the potential impact of integration with public transportation. For example, some studies have observed that e-bikes complement public transport, while others have found that they replace it altogether [39].

4.3. Classification Approach

During the analysis process, the literature was systematically categorized into five core themes: (1) Infrastructure and Technological Components, (2) Behavior and Acceptability, (3) Environmental and Social Impacts, (4) Policy, Planning, and Decision-Making, (5) Applied Case Studies and Optimization Models. These also enabling comparisons of themes provide a holistic understanding of smart mobility stations, while various implementations and recommendations within different contexts under each category. The categories were selected to comprehensively reflect the multidisciplinary nature of mobility stations, encompassing technological infrastructure, user behavior and acceptability, environmental and social impacts, policy and planning processes, and applied optimization models. This classification allows for an integrated analysis of both the technical components (such as infrastructure and technological integration) and the user-centric and sustainability aspects of mobility stations [77-78-79]. Furthermore, incorporating policy and planning perspectives is critical for enhancing the effective implementation of mobility stations at the urban scale [80]. Applied case studies and optimization models play a key role in assessing operational efficiency and system performance.

The categories selected for mobility research are carefully structured to reflect the multidimensional nature of the field. Infrastructure and technological components play a critical role in determining the feasibility and efficiency of mobility solutions [81]. User behavior and acceptability help to understand the societal adoption of new transportation systems by analyzing individuals' perceptions and habits [82]. Environmental and social impacts offer a sustainability perspective by addressing issues such as carbon emissions, air pollution, and social equity [83]. The category of policy, planning, and decision-making highlights the role of governance, regulation, and strategic planning in the development and implementation of mobility systems [84]. Finally, applied case studies and optimization models demonstrate how theoretical approaches operate in practice, providing tangible insights for policymakers and planners [85]. Taken together, these categories enable a comprehensive evaluation of mobility solutions across technical, social, environmental, and institutional dimensions.

4.3.1. Thematic Analysis of Classification Outcomes

The thematic framework enabled a multidimensional exploration of the smart mobility station paradigm and facilitated comparative insights across varying geographical and policy contexts.

Infrastructure and Technological Components: This category encompasses foundational elements such as charging infrastructure, sensor integration, data communication systems, and intermodal connectivity. A significant proportion of the literature emphasizes the role of IoT, AI-based scheduling systems, and real-time data platforms [86-87]. The prevalence of such technologies is especially critical in densely populated urban settings where infrastructure scalability and interoperability determine service effectiveness.

User Behavior and Acceptability: Studies under this theme focus on the human-centric dimension, examining factors such as willingness to adopt, perceived ease of use, and trust in autonomous or semi-autonomous systems. Findings suggest that socio-demographic factors, prior exposure to smart systems, and perceived environmental benefits strongly influence user uptake [88-89]. Moreover, the importance of usability, accessibility, and affordability emerged as cross-cutting issues impacting behavioral adoption rates.

Environmental and Social Impacts: Research in this domain evaluates how smart mobility stations contribute to reducing carbon emissions, improving air quality, and promoting social equity. Empirical findings indicate a clear correlation between smart mobility deployment and improved environmental indicators in urban corridors [90]. Nevertheless, some case studies highlight the risk of spatial inequality, whereby high-income districts receive preferential access to high-tech infrastructure [91].

Policy, Planning, and Decision-Making: This category synthesizes the role of institutional frameworks, governance models, and strategic planning in shaping the deployment of mobility stations. Literature emphasizes the necessity of cross-sectoral collaboration and long-term visioning to ensure infrastructure coherence and public accountability [92-93]. Regulatory harmonization and funding mechanisms also surface as critical enablers for sustained implementation.

Applied Case Studies and Optimization Models: Finally, numerous contributions employ simulation models, GIS-based location analysis, and optimization algorithms to assess real-world applications. These studies often provide actionable insights on station placement, fleet sizing, and network design efficiency [94]. Comparative case studies from Europe, North America, and East Asia offer diverse learning pathways and contextual adaptations.

The five-category thematic framework offers a holistic lens through which the evolving discourse on smart mobility stations can be understood and operationalized. This structure not only captures the technical and human dimensions but also highlights the interplay between policy and practice. Future research should aim to integrate these categories more systematically, particularly through interdisciplinary approaches that bridge engineering, urban studies, and behavioral sciences.

4.4. User Behavior and Socio-Demographic Factors

The success of electric mobility stations (smart mobility stations) is closely linked not only to infrastructure quality and technological integration but also to the behavioral tendencies and socio-demographic characteristics of the individuals using these systems. In the literature, the attitudes of users towards these systems, the reasons for their preferences, and their behavioral patterns have been studied in detail.

4.4.1. Demographic Characteristics

Many studies show that station usage tends to align more with specific user profiles. In particular:

- Young individuals (aged 18–34),
- Those with a higher level of education,
- Individuals from middle and higher income groups,
- People who do not own a vehicle or have limited access to one,

are more likely to adopt station systems [22-57].

These groups also tend to be environmentally conscious, open to innovation, and inclined towards multimodal travel behaviors. These users prefer shared e-vehicles for short to medium-distance trips, such as daily commuting, shopping, or attending social events.

4.4.2. Psychological and Attitudinal Factors

Studies have shown that environmental awareness, openness to innovation, pro-public transport attitudes, and positive perceptions of shared mobility are key determinants in the adoption of station systems [24-95]. However, users who do not prefer shared modes often highlight the following barriers:

- Insufficient information and digital skills,
- Long walking distances and access times,
- Safety and hygiene concerns,
- System complexity and user interface issues.

4.4.3. Reasons for Use and Mode Preferences

Users generally express their reasons for preferring smart mobility stations as follows:

- Cost advantage, particularly savings on fuel and maintenance expenses,
- Offering an environmentally friendly alternative,
- Flexibility and convenience in vehicle sharing,
- The ability to combine use with public transport (especially for commuting purposes) [96].

Studies by Liao *et al.,* [72] highlight the complementarity between different modes of transport offered at smart mobility stations. For instance, a person using a shared e-bike may choose to use an e-vehicle from the same hub during unfavorable weather conditions. This demonstrates that the flexibility factor increases users' attachment to station systems.

4.4.4. Behavioral Transformation Potential

Experimental studies conducted by Franken [76] found that individuals living in city centers and suburbs, particularly those with low monthly vehicle usage, are more likely to switch from private cars to station systems. Furthermore, when the system is affordable and accessible, this behavioral shift is more likely to occur. As a result of the literature review, topics related to mobility stations, the authors referencing these topics, and the corresponding inferences are presented in Table 6.

Overall, the limited number of studies on Smart Mobility Stations (SMS) in developing countries can be attributed to several interrelated factors. First, the high initial infrastructure and implementation costs associated with integrated mobility systems often pose a significant barrier in resource-constrained urban environments. Second, differing urbanization patterns, characterized by rapid and often unplanned urban growth, limit the applicability of standardized mobility station models. Third, institutional and governance challenges, including fragmented decision-making structures and limited inter-agency coordination, further constrain the development of such systems. Finally, varying levels of technological readiness and digital infrastructure also play a critical role in shaping the adoption of SMS in developing contexts. These factors collectively help explain the observed geographical imbalance in the literature and highlight the need for context-sensitive approaches in future research.

Table 6
The key issues related to mobility stations and the authors associated with these topics

Issue	Authors	Result
INTEGRATION		
Integration with Public Transport **Integration of smart mobility stations** **Integration of digital applications** **Multimodal integration** **Support for digital platforms**	Ladder [15]; Coenegrachts *et al.,* [20]; Roukouni *et al.,* [25]; Shah *et al.,* [45]; Liao and Correia [57]	The physical and digital integration of mobility stations with public transport systems plays a key role in ensuring mobility continuity. Regulatory uncertainties, conflicts over the use of public spaces, and low digital accessibility are major barriers to the integration of smart mobility stations.
ADOPTION AND BEHAVIORAL TRANSFORMATION		
User Behavior **User Engagement** **Acceptability** **Use and mode preferences** **User-centric perspective** **Access Ease** **Location Selection**	Ladder [15]; Shah *et al.,* [45]; Liao *et al.,* [72]; Franken [76]; Garritsen, [96]; Bösehans *et al.,* [97]	Surveys and logistic modeling analyze the rate at which users transition from private cars to shared modes. Criteria such as access time, parking convenience, and walking distance directly influence user satisfaction. Research shows that station-based systems are more likely to be adopted by young adult, individuals with higher education, middle- to high-income groups, and those without personal vehicle access. These users tend to be environmentally conscious, open to innovation, and favor multimodal travel, often choosing shared electric vehicles for short- to medium-distance trips such as commuting, shopping, or social activities. Additionally, digital reservation and user experience applications are key factors that enhance the adoption of Mobility Stations
INFRASTRUCTURE		
Charging infrastructure **Technological Components** **Infrastructure investments** **Support for digital platforms**	Esfandi *et al.,* [74]; Guerrero-Ibanez *et al.,* [75]; Coenegrachts, [99]; Grilli and Curtis [100]; Litman, [101-103]	Mobility stations must be conceptualized beyond mere transportation hubs, serving as essential components of urban infrastructure. Investments in both infrastructure and superstructure should adhere to principles of equity, social justice, and inclusivity, which are crucial within the framework of urban transportation and mobility.
POLICY, PLANNING, DECISION-MAKING		
Regulatory barriers **Inadequate governance processes** **Public-private partnerships** **Designs and implementations** **Participatory planning** **Flexible business model designs** **Planning for public charging stations** **Tax reductions and subsidies**	Coenegrachts *et al.,* [20]; Toering *et al.,* [21]; Roukouni *et al.,* [25]; Guerre;ro-Ibanez *et al.,* [75]; Coenegrachts, [99]; Grilli and Curtis [100]	Effective implementations of mobility stations exhibit several shared attributes. Specifically in Europe, cooperative efforts among public authorities, transportation agencies, private e-mobility operators, urban planners, and local communities are contributing to the increased sustainability of station-based initiatives.
SUSTAINABILITY AND ENVIRONMENT		
Reducing car dependency **Carbon emissions, decarbonization** **Promoting multimodal transportation** **Environment, Energy consumption** **Cost and Economic Sustainability**	Ladder [15]; Shah *et al.,* [45]; Liao *et al.,* [72]; Hosseini and Caulfield [73]; Xanthopoulos *et al.,* [98]	The capacity of mobility stations to replace private car usage is measured by the reduction in direct CO_2 emissions. Service usage costs, maintenance and operational expenses, and public and private sector investments are assessed.

5. Policy, Planning, and Integration Models

The successful implementation of station systems depends not only on technological infrastructure and user demand but also on effective policymaking, governance mechanisms, and urban planning strategies. The literature emphasizes that shared mobility stations should be approached with a multi-actor, multi-level, and interdisciplinary framework.

5.1. Multi-Actor Decision-Making and Stakeholder Participation

The "4P" framework developed by Arnold *et al.,* [64] Purpose, Process, Place, and Performance provides a systematic approach to policymaking. This framework emphasizes the customization of station implementations according to contextual needs and highlights the importance of public-private partnerships, community involvement, and institutional coordination in decision-making processes. In particular, in Europe, collaborations established between public authorities, transport agencies, private e-mobility providers, urban planners, and citizens are enhancing the sustainability of station projects [20].

5.2. Positioning Strategies and Planning Models

The positioning of smart mobility stations in urban planning is done using advanced tools such as Geographic Information Systems (GIS), Multi-Criteria Decision Analysis (MCDA), and genetic algorithms [40-98]. These models consider the following criteria when selecting locations:

- Population density and user potential,
- Proximity to public transport stops,
- Land use structure,
- Demand forecasts and user behavior patterns.

For example, a methodology developed in the Netherlands combines the perspectives of end-users, operators, and local governments using the Analytic Hierarchy Process (AHP) to evaluate location suitability [40].

5.3. Policy Incentives and Legal Framework

The widespread adoption of station systems is also heavily influenced by legal regulations and policy incentives. These incentives include:

- Tax reductions and subsidies,
- Infrastructure investments,
- Support for digital platforms,
- Planning for public charging stations,
- Information and awareness campaigns [99-100].

However, the literature also highlights that regulatory uncertainties, conflicts over the use of public spaces, and low digital accessibility are major barriers to the integration of smart mobility stations [25].

6. Conclusion and Strategic Policy Recommendations

The concepts of e-stations and mobility play a central role in future urban planning as structures that make urban transportation smarter, more integrated, and more sustainable. The widespread adoption of these systems will not only create a technological transformation but also a social, environmental, and governance transformation. In this context, e-stations should be regarded not only as transportation stations but also as vital infrastructure for urban living.

This study provides a comprehensive evaluation of the role of smart mobility stations in the transformation of urban mobility, considering them from a multidimensional perspective, based on current studies in the literature. Shared e-mobility stations have strategic potential in promoting sustainable transportation, reducing private vehicle use, lowering CO_2 emissions, and developing integrated mobility solutions with public transportation.

Infrastructure and superstructure investments should be made in accordance with the concepts of equality, social justice and participation, which are of critical importance and should not be ignored in the context of urban transportation and mobility, and should be designed in a way that allows physical, cultural, social and economic access for all segments of society. According to Litman [101-103], who addresses the concept of equality in two dimensions as horizontal equality and vertical equality, in order to provide a structure in accordance with the concept of equality in mobility, it is necessary to focus on the factors of "fair share, external costs, inclusivity, affordability and social justice".

The analysis shows that the success of station systems depends not only on infrastructure but also on managerial, social, and technological factors. Multi-actor and participatory approaches in planning processes, proper location selection, appropriate pricing, and digital integration are key elements that stand out in ensuring the effectiveness and sustainability of these systems.

Strategic Policy and Implementation Recommendations:

1. The integration of multimodal systems should be supported, and smart mobility stations should be physically and digitally connected to public transportation and active transportation modes.
2. Planning models tailored to local needs should be developed, ensuring that smart mobility stations are positioned in alignment with criteria such as population density, socio-demographic structure, and land use.
3. Socioeconomic inclusivity should be ensured, and accessibility policies should be developed to allow disadvantaged groups to benefit from these systems.
4. Public-private partnerships should be supported, and sustainable business models should be established to ensure long-term operational success.
5. City governments should invest in data collection, analysis, and monitoring systems to support evidence-based decision-making processes.

In line with global climate goals, it has become a necessity for cities to make their transportation systems more environmentally friendly, accessible, and efficient. station systems are not just a part of this transformation but also a catalyst for it. However, the widespread adoption of these systems will not be possible through technological investment alone; it will also require human-centered, equitable, and flexible planning processes. Therefore, it is crucial for future studies, both at the academic and practical levels, to focus on producing inclusive, interdisciplinary, and contextually aware models.

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