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# NEW CHALLENGES FOR XXI CENTURY CITIES

## Multilevel scientific approach to impacts of global warming on urban areas, energy transition, optimisation of land use and emergency scenario

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TeMA Journal was established with the primary objective of fostering and strengthening the integration between urban transformation studies and those focused on mobility governance, in all their aspects, with a view to environmental sustainability. The three issues of the 2025 volume of TeMA Journal propose articles that deal with the effects of Global warming, reduction of energy consumption, immigration flows, optimization of land use, analysis and evaluation of civil protection plans in areas especially vulnerable to natural disasters and multilevel governance approach to adaptation.

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**Editorial correspondence**
Laboratory of Land Use, Mobility and Environment
DICEA - Department of Civil, Building and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples (Italy)

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The cover image shows a composition of two photos of the Temple of Serapis in Pozzuoli (Italy). Giuseppe Mazzeo took them in January 2009 and March 2025. At the top, the 2009 image shows the temple flooded, with the pavement not visible. In the down, the 2025 image shows the temple’s pavement dry and exposed. The Temple of Serapis is one of the leading visual indicators of the bradyseism phenomenon in the Phlegraean Fields. The bradyseism phase, highlighted by comparison, started in the first years of this century, as shown by the data published by the National Institute of Geophysics and Volcanology (INGV) on the website dedicated to the phenomena (https://www.ov.ingv.it/index.php/il-bradisismo).

TeMA - Journal of Land Use, Mobility and Environment offers researches, applications and contributions with a unified approach to planning and mobility and publishes original inter-disciplinary papers on the interaction of transport, land use and environment. Domains include: engineering, planning, modeling, behavior, economics, geography, regional science, sociology, architecture and design, network science and complex systems.
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# Mobilising equity. Emerging evidence for integrating vulnerable communities

**Irina Di Ruocco**

Department of Economics,
University of Insubria, Varese, Italy
e-mail: diruocco@uninsubria.it
ORCID: https://orcid.org/0000-0003-0829-0754

**Abstract**
The transition towards sustainable cities is progressing, with numerous smart city technologies and innovative concepts being implemented. However, these advancements have predominantly focused on urban areas, often overlooking the critical need for integrating transportation systems with surrounding rural regions. Equitable access for vulnerable populations in peripheral areas remains underexplored, with most research focusing on the elderly while neglecting other vulnerable groups such as ethnic and gender minorities, women, young people, and individuals with serious health conditions. Empirical evidence shows that many rely on private transportation or are confined to small, localized areas. This article, through a literature review, analyses emerging research evidence on transportation for vulnerable groups, emphasizing the need to integrate technological solutions for individuals with reduced mobility (e.g. such as the visually impaired) into digital mobility platforms and land-use planning. The study highlights the lack of focus on rural regions and diverse vulnerable groups, stressing the importance of better integrating technology and land-use planning to improve transportation accessibility.

**Keywords**
Vulnerable groups; Accessibility; Mobility inclusive; Sustainable mobility; Policies.

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## 1. Introduction

The connection between transportation systems, land use, and mobility is fundamental for fostering social inclusion and well-being (Preston & Rajé, 2007). Efficient transportation access is essential for participation in key daily activities, such as healthcare, employment, and recreation (Gatrell, 2013; Papagiannidis et al., 2017). However, approximately 16% of the global population, including individuals with physical, sensory, or cognitive impairments, economically disadvantaged groups, and ethnic minorities, face restricted mobility options, limiting their ability to access essential services (WHO, 2021). This issue is expected to intensify with demographic changes, including aging populations and rising non-communicable diseases (He et al., 2020).

Accessibility challenges persist, particularly in low-income and underserved areas (Martens, 2019), where infrastructure investments are minimal, leading to high travel costs and extended commute times (El-Geneidy et al., 2016). Despite technological advancements (Oguz & Tanyas, 2024), marginalized groups continue to face systemic barriers, including financial limitations, physical inaccessibility (Soltani et al., 2012), and discriminatory practices. Technologies such as Intelligent Control Technology "ICT" and Augmented Reality "AR" offer promising tools, but their adoption often fails to address the specific needs of diverse vulnerable populations, especially in rural contexts (Nixon & Schwanen, 2018; Ma et al., 2018). Moreover, the COVID-19 pandemic further exposed the vulnerability of transportation systems, particularly for the elderly (LaPlante, 2014), immunocompromised, and those experiencing intersecting forms of marginalization (Beck & Hensher, 2020). This highlights the urgent need for resilient and inclusive infrastructure that caters to diverse user needs.

Understanding mobility vulnerabilities requires an intersectional approach to examine how social identities like gender, race, disability, and economic status intersect, creating compounded barriers to transportation access (Crenshaw, 1991; Sheller, 2018). For example, low-income women may face financial, cultural, and safety challenges, while ethnic minorities or individuals with disabilities may encounter discrimination limiting their mobility. Addressing these inequalities demands targeted strategies that consider these overlapping factors. (D'Agostino et al., 2024).

However, empirical studies lack comprehensive evaluations of technology adoption rates among economically disadvantaged or elderly users. Yet, evidence on how new design changes have tangibly improved daily mobility outcomes for vulnerable populations remains limited. Globally, policy innovations and best practices (BPs) offer valuable lessons for addressing mobility challenges, yet their impacts remain underexplored. The selected examples stand out for their integration of inclusivity and technological innovation, demonstrating measurable outcomes while addressing physical and digital barriers to mobility. In Finland, the Whim app integrates diverse transport modes into a seamless, multi-modal platform with flexible fare structures, reducing travel barriers and enhancing convenience. However, scalability and affordability remain challenges. Barcelona's accessible metro system exemplifies universal design principles, improving accessibility for mobility-impaired users, though long-term maintenance remains critical. In Medellín, the Metrocable system connects low-income hillside communities with central hubs, reducing travel times and improving access to education and healthcare. However, questions about subsidy sustainability persist.

São Paulo's community-led BRT system emphasizes participatory planning, fostering community ownership and localized solutions, though consistent institutional commitment is essential. In London, the contactless payment system enhances efficiency and reduces boarding times but lacks comprehensive analysis of its impact on low-income users (Moore et al., 2013). Similarly, Los Angeles' electric bus initiative offers environmental benefits but requires deeper evaluation of equity outcomes.

These cases reveal key lessons: inclusivity must be embedded from the outset, technology serves as an enabler but must remain accessible, and long-term financial sustainability is essential. Additionally, community participation strengthens adoption and trust. While these BPs are context-specific, they offer adaptable frameworks for designing equitable, efficient, and sustainable mobility systems. Future research should focus on evaluating these dimensions to ensure broader applicability and long-term impact.

While these examples highlight promising interventions, they are often presented in fragmented narratives, lacking systematic evaluation frameworks to assess their long-term impacts on accessibility, social inclusion, and resilience. This paper addresses this analytical gap through a comprehensive literature review, incorporating academic and grey literature, including policy documents and case studies that explicitly focus on these dimensions but remain underexplored empirically.

The analysis focuses on three key dimensions (Litman, 2022; Lucas, 2011):

a) Equity-focused policies addressing disparities related to age, health, gender, and economic status to ensure fair mobility access;
b) Community engagement frameworks that align mobility solutions with the lived experiences of vulnerable groups, fostering trust and sustainable adoption;
c) Technology adoption strategies designed to bridge urban-rural divides and promote inclusive digital accessibility.

This study contributes to a deeper understanding of how transportation systems can reduce mobility inequalities and enhance social inclusion, advocating for further empirical research to validate these insights across diverse geographical and socio-economic contexts.

The central research question (RQ) guiding this study is: "How can technological and digital mobility solutions for users with reduced mobility be integrated into transportation systems to enhance accessibility for vulnerable populations, particularly in underserved urban and rural areas?".

The study structure is as follows. After this introduction, Section 2 describes the empirical background on current trends. Section 3 outlines the methodology. Section 4 discusses the results and discussion. Section 5 concludes with recommendations for policymakers, urban planners, and stakeholders to create equitable, inclusive, and sustainable mobility systems.

## 2. Background

The concept of social vulnerability includes not only "vulnerable populations" but also fragile individuals, such as the elderly with reduced mobility, the visually impaired, and the immunocompromised. Addressing their needs relies on technologies like Mobility-as-a-Service (MaaS), Artificial Intelligence (AI), and machine learning, which offer tailored navigation tools. However, these technologies remain only partially integrated into transportation systems, limiting their accessibility and effectiveness.

Despite advances in digital route assistance, elderly and visually impaired users still face significant barriers, especially in areas with poor technological infrastructure. Public transport systems often fail to accommodate immunocompromised individuals, pushing them to rely on private vehicles. In rural areas, and highlighted by O’Neill & O’Mahony (2005) for Ireland, the limited deployment of transport technologies further restricts mobility options and access to essential services.

While mobility planning increasingly prioritizes accessibility and equity, integrating trends such as ecological mobility and active transportation remains challenging for fragile groups. The adoption of ICT, MaaS, and Big Data technologies is still limited, preventing scalable and inclusive solutions.

The condition of mobility poverty reflects a lack of reliable, affordable, and sustainable transportation options, constrained by spatial, economic, technological, and cultural barriers (Kuttler & Moraglio, 2023). Overcoming these barriers requires integrated, equity-focused strategies to ensure accessible mobility for all.

From a spatial and geographic perspective, mobility barriers are distributed unevenly, with rural and peri-urban areas suffering from inadequate infrastructure and unreliable transit networks (O'Neill & O'Mahony, 2005). These deficits often force residents to rely on private vehicles, increasing financial burdens and environmental degradation. In contrast, urban centers face different but equally challenging issues, including overcrowded networks and limited last-mile connectivity.

The economic dimension highlights the burden of transportation costs on low-income populations, who often cannot afford private vehicles or costly urban transit fares. Maintenance expenses, combined with the financial pressures of transit access, exacerbate existing inequalities (Lucas, 2011). These economic barriers frequently overlap with spatial disparities, intensifying social exclusion (Ignaccolo et al., 2016).

In the technological sphere, innovations like Mobility-as-a-Service (MaaS) and AI-driven mobility tools offer solutions for optimizing transit routes, improving flexibility, and enabling adaptive services. Multiple transport services into a single platform, simplifying travel for users (Sen et al., 2022). However, challenges such as digital literacy gaps, limited infrastructure readiness, and financial barriers prevent widespread adoption, especially in rural and underserved areas (Park et al., 2022).

The environmental dimension focuses on the sustainability challenges associated with mobility poverty. In regions where public transport is sparse or unreliable, dependency on private vehicles leads to increased carbon emissions and worsened air quality. At the same time, sustainable infrastructure—such as cycling lanes and pedestrian pathways—remains underdeveloped in vulnerable regions, further limiting accessible options (Titheridge et al., 2014).

The social and cultural dimension reflects barriers rooted in discrimination, safety concerns, and cultural exclusion, particularly for women, ethnic minorities, and migrants. Poorly lit transit stops, limited language assistance, and systemic biases in planning disproportionately impact these groups, reinforcing their exclusion from mobility networks. According to D'Agostino et al. (2024) women in advanced countries tend to travel shorter distances, make more daily trips, use cars less frequently, and are more willing to adopt sustainable travel behaviours than men.

To address these interconnected barriers, land-use planning and transportation systems must be integrated effectively. Mixed-use development reduces travel distances to essential services, while Transit-Oriented Development (TOD) enhances connectivity and encourages reliance on sustainable transit options. Cerdá et al. (2012) describing Medellín's Metrocable system, demonstrate the potential of TOD policies to improve spatial connectivity and inclusion. However, without complementary housing and affordability policies, TOD strategies risk triggering gentrification and displacement, ultimately excluding the very populations they aim to serve (Vecchio & Martens, 2021).

Technological advancements like MaaS platforms and AI tools offer additional opportunities to bridge mobility gaps. For individuals with motor, sensory, or cognitive impairments, MaaS platforms provide real-time updates on accessible routes, while AI-driven systems optimize service delivery and route planning to accommodate demand fluctuations (Park et al., 2022). However, these technologies remain underutilized in rural and marginalized areas, where affordability and digital literacy gaps persist. Evidence in European cities (e.g., Toronto and Barcelona) shows how policy initiatives can reduce financial and infrastructure barriers. Toronto's fare subsidy has notably improved transit affordability for low-income users (Barri et al., 2021), while Barcelona's station redesigns increased transit usability for individuals with mobility impairments by 27% (Comim, 2008). Nevertheless, both cases emphasize the importance of sustained investment and community engagement to ensure long-term success. Examples like London's contactless payment system and Los Angeles' electric bus initiative highlight how technology and environmental goals can intersect with social equity, albeit with limitations in reaching marginalized communities (Bezbradica & Ruskin, 2019; Allen & Farber, 2020).

Addressing mobility poverty requires a multi-faceted strategy that combines targeted technological integration, policy alignment, and sustained infrastructure investment. The next section will build upon these insights, presenting evidence-based findings from the literature to highlight effective strategies for overcoming mobility barriers and fostering inclusive transportation systems.

Building on the earlier discussion, social vulnerability and mobility poverty are deeply interconnected, as limited transportation access amplifies exclusion from economic, social, and cultural activities. Vulnerable groups, including older adults, individuals with physical, sensory, or cognitive impairments, economically disadvantaged populations, women (D'Agostino et al., 2024), youth, and ethnic minorities, face compounded barriers due to inadequate infrastructure, affordability constraints, and systemic exclusion (Battarra et al., 2018; Park & Chowdhury, 2018).

Globally, well-planned transportation systems have shown potential to improve access to employment, healthcare, and education, fostering social inclusion and economic growth (Cerdá et al., 2012; Vecchio & Martens, 2021). Investments in accessible metro systems and fare equity programs demonstrate positive outcomes, but their scalability remains limited (Comim, 2008; Barri et al., 2021).

Technological innovations, including Mobility-as-a-Service (MaaS) and digital payment systems, offer promising solutions. However, while affluent users benefit from seamless integration, low-income populations often face financial barriers, limiting their accessibility and equity impact (Arai et al., 2022).

Addressing these challenges requires integrated strategies that bridge spatial, economic, and technological divides to ensure inclusive, accessible, and resilient mobility systems. Further empirical research is essential to validate these approaches and assess their effectiveness across diverse contexts.

# 3. Methodology

## 3.1 Identification of target groups

In line with the literature review methodology described, this section identifies the key vulnerable groups facing mobility barriers and transport poverty, drawing from established literature (Hine & Mitchell, 2016; Lucas et al., 2016; Van Wee & Geurs, 2011). These studies emphasize how systemic inequalities, infrastructural limitations, and socio-economic disparities create persistent mobility challenges for marginalized populations.

The specific user groups analysed include:

1. Individuals with Disabilities: People with mobility, sensory, or cognitive impairments who encounter physical and infrastructural barriers within transportation systems (Currie et al., 2010);
2. Economically Disadvantaged Populations: Communities with limited financial resources, often disproportionately affected by high transport costs and underfunded infrastructure (Lucas, 2012);
3. Elderly Populations: Older adults whose physical and cognitive limitations, coupled with transport design barriers, restrict their independent mobility (Shergold & Parkhurst, 2012);
4. Women and Youth: Groups facing social and cultural barriers, including safety concerns, caregiving responsibilities, and financial dependence (Uteng & Cresswell, 2008);
5. Ethnic Minorities and Marginalized Communities: Populations experiencing systemic discrimination and cultural exclusion in accessing transportation services (Soja, 2013; Oviedo & Sabogal, 2020);
6. Residents in Rural or Remote Areas: Individuals in low-density regions where public transport services are often unreliable, sparse, or economically unfeasible (Nutley, 2003).

As shown in Tab.1, these user groups were selected based on their documented vulnerabilities in global policy discussions on mobility justice, their prominence in academic research, and their alignment with sustainable transport strategies (Jones et al., 2018; Lucas, 2012). These references highlight the interconnected nature of social equity, mobility access, and transport infrastructure investment, providing a robust foundation for this analysis. These groups represent the focus of the reviewed studies and provide a foundation for analyzing mobility-related social exclusion and accessibility challenges. Tab.1 summarizes their barriers, spatial contexts, and rationales:

1. Low-income and Unemployed Individuals:
- Barrier. High transportation costs, limited public transport access;
- Spatial Context. Urban reliance on public transit; rural dependence on car ownership;
- Rationale. Transport costs exacerbate poverty and reliance on inefficient systems (Lucas et al., 2016). In 2022, 21.7% of the EU population faced poverty risk (Eurostat, 2022).

2. Elderly Persons, Women, and Gender-Diverse Groups:
- Barrier. Physical infrastructure issues, safety concerns, limited services;
- Spatial Context. Urban and rural areas, with acute challenges in low-density zones;
- Rationale. Women face safety concerns, while elderly individuals encounter physical barriers. In 2021, 22.7% of women in the EU faced poverty risk (Eurostat, 2022).

3. Young People (16-24 years):
- Barrier. Financial dependence, restricted access to transport options;
- Spatial Context. Urban and suburban areas with infrequent transit services;
- Rationale. Limited financial independence hinders youth mobility (Eurostat, 2022).

4. Migrants and Ethnic Minorities:
- Barrier. Language barriers, financial constraints, cultural discrimination;
- Spatial Context. Predominantly urban areas with uneven transport access;
- Rationale. Reduced access due to financial and language challenges. In 2021, 5.3% of the EU population were non-EU citizens (Eurostat, 2022).

5. People with Reduced Mobility:
- Barrier. Inadequate infrastructure, lack of adapted services, technological exclusion;
- Spatial Context. Urban architectural barriers; poor rural services;
- Rationale. Specially adapted services are essential for equitable mobility. In 2021, 29.7% of disabled individuals in the EU faced poverty risk (Eurostat, 2022).

6. Residents of Rural, Disadvantaged, and Marginal Urban Areas:
- Barrier. Sparse networks, low transit frequency, long travel times;
- Spatial Context. Rural and peripheral areas with limited services;
- Rationale. Poor infrastructure limits access to essential services. In 2018, 29.1% of EU residents lived in rural areas (Eurostat, 2022).

7. Immunocompromised Individuals:
- Barrier. Safety and hygiene concerns in shared transport systems;
- Spatial Context. Urban and rural environments, with higher risks in crowded settings;
- Rationale. Safe travel conditions are essential but often unmet (Pezzagno & Richiedei, 2022).

These groups highlight the multifaceted barriers to mobility, emphasizing the need for targeted strategies to address their unique challenges across urban, suburban, and rural contexts.

## 4. Results and discussion

This section describes the results of the methodology, highlighting the role of policy-driven mobility solutions in overcoming barriers faced by older adults, individuals with impairments, economically disadvantaged populations, women, youth, and ethnic minorities.

| Keyword Sector | Target Groups | Area of Interest | Quantitative Methods | Qualitative Methods | Focus of Vulnerability | Data Collection Method | Example References | No. of Papers Reviewed |
|---|---|---|---|---|---|---|---|---|
| Land-Use Integration | Economically disadvantaged groups | Transport policies, geography | ✓ | ✓ | Socio-economic exclusion | Travel survey, GIS | El-Geneidy et al., 2016; Welch & Mishra, 2013 | 12 |
| Gender and Youth Mobility | Women, Youth | Behavioral science | ✓ | ✓ | Gender-specific barriers, safety | GPS tracking, Interviews | Vecchio & Martens, 2021; Park et al., 2022 | 10 |
| Assistive Transport Tools | Individuals with impairments | Health, accessibility | ✓ | ✓ | Mobility, cognitive, sensory barriers | Questionnaire, Interviews | Li & Loo, 2017; Park & Chowdhury, 2018 | 8 |
| Marginalized Communities | Ethnic minorities | Co-design, urban planning | ✓ | ✓ | Systemic and cultural exclusion | Travel survey, Focus groups | Nixon & Schwanen, 2018; Hananel & Berechman, 2016 | 9 |
| Spatial Accessibility | Rural and remote communities | Regional geography | ✓ | ✓ | Infrastructure and distance barriers | Travel survey, GIS | Combs et al., 2016; Papa et al., 2018 | 7 |
| Inclusive Policy Frameworks | Elderly | Social inclusion policies | ✓ | ✓ | Age-related accessibility barriers | Community workshops | Battarra et al., 2018; Shareck et al., 2014 | 6 |
| Regulatory Policies | Cross-cutting (multiple groups) | Regulation, urban policy | ✓ | ✓ | Institutional and policy gaps | Document analysis | Di Ciommo & Shiftan, 2017; Allen & Farber, 2020 | 13 |

✓: Indicates that studies within the category utilized the specified methodological approach.

**Tab.1 Overview of Reviewed Studies by Keyword Sector, Target Groups, and Methodologies (Elaboration of author)**

The key findings of this research align with the five thematic dimensions (4.1–4.5) and offer an integrated framework for addressing mobility challenges:

1. Equitable transportation systems are essential for improving access to social, economic, and cultural opportunities. This aligns with Section 4.1: Policy-Oriented Mobility Targeting Vulnerable Groups, which emphasizes the role of targeted policy interventions, and Section 4.2: Accessibility and Proximity in Smart Cities, which focuses on spatial planning and urban design to minimize mobility barriers;
2. Active community participation ensures mobility solutions are aligned with the lived experiences and needs of end users. Section 4.5: Technology and Community Engagement explores participatory approaches to policymaking, while Section 4.4: Spatial and Infrastructure Resilience underscores how community input strengthens adaptability and responsiveness in infrastructure development;
3. Innovations such as Mobility-as-a-Service (MaaS) and ICT platforms offer scalable solutions to bridge mobility gaps. Section 4.3: Mobility Technologies for Vulnerable Groups examines these technologies' role in improving transport efficiency and inclusivity, while Section 4.4: Spatial and Infrastructure Resilience highlights the importance of context-specific implementation to address rural-urban disparities.

Together, these dimensions—policy frameworks (4.1), spatial planning (4.2), technological integration (4.3), infrastructure resilience (4.4), and community engagement (4.5) - form an interconnected strategy for combating mobility poverty. Each dimension contributes uniquely: policy provides direction, spatial planning ensures physical accessibility, technology drives innovation, resilient infrastructure sustains long-term access, and community engagement guarantees inclusivity and relevance. The following section builds on these insights, offering specific recommendations and actionable pathways to implement inclusive mobility solutions effectively. Lastly, the discussion proposes also an evaluation of different challenges across the types of regions, and the future development for research (4.7).

## 4.1 Policy oriented mobility targeting for vulnerable groups

Policy-oriented mobility focuses on tailored transport policies designed to address the unique needs of vulnerable groups. For instance, Toronto's Fair Pass program subsidizes public transit for low-income users, reducing financial barriers (Barri et al., 2021), while Barcelona's metro upgrades improved usability for individuals with impairments by 27% (Comim, 2008).

However, policy effectiveness depends on clear metrics for accessibility and ongoing evaluation. Initiatives like Finland's Whim app demonstrate how MaaS platforms can offer integrated services, but questions remain about who drives these initiatives and how accessibility outcomes are measured (Sen et al., 2022).

Emerging trends in urban mobility, as outlined in the "POLIS Report" (Polis, 2021) and the EIT Report (EIT Urban Mobility, 2021), emphasize integrating resilience into sustainable urban mobility planning. These reports explore strategies for post-COVID mobility systems, highlighting best practices from European cities (Budd & Ison, 2020; Pan & He, 2022; Beck & Hensher, 2020). A key focus is on inclusiveness and integration, ensuring vulnerable groups are considered in urban and rural transport planning. Public transport remains vital for people with special needs, providing access to jobs, education, and social opportunities in disadvantaged areas. The MaaS sector is exploring accessibility measures, such as the Urban Mobility Index and Deloitte's City Mobility Index (Dixon et al., 2019), but these have yet to fully address the needs of vulnerable users. EU guidelines (2014) emphasize accessibility through user-centered design, including digital devices, audible/visual announcements, and affordability. The co-creation approach encourages civic participation, allowing communities to co-identify needs, co-develop solutions, and co-evaluate outcomes (EU, 2019). Community policies focus on reducing digital exclusion by improving access to technology, enhancing digital literacy, and ensuring adequate infrastructure. The European Accessibility Act (Directive (EU) 2019/882 (European Union - Regulation 2019) and the Regulation on Technical Specifications for Interoperability (EU, 2014) further support accessibility in transportation for people with disabilities.

## 4.2 Accessibility and proximity of smart cities

In smart city planning, accessibility serves as a core metric for evaluating the connection between people, territories, and transportation systems, while proximity, mobility, and connectivity represent the tools and processes enabling access. Accessibility, often considered an end goal, reflects the ability of individuals to reach essential services and opportunities efficiently and equitably, whereas mobility represents the movement itself, and proximity indicates the spatial arrangement of services relative to users.

Successful accessibility planning requires a shift from mobility-centered approaches to access-oriented frameworks, where the emphasis is placed on the capacity of transportation systems to meet social equity objectives. For example, Bocarejo & Oviedo (2012) developed a tool to analyze transport accessibility and social inequities, demonstrating how infrastructure and costs often limit access despite geographical proximity. Similarly, Sochor (2015) highlighted access deprivation through semi-structured interviews with disadvantaged populations, emphasizing the need to address both physical and economic barriers to access.

At the urban scale, Transit-Oriented Development (TOD) remains a widely adopted strategy to improve proximity and spatial accessibility by clustering housing, employment, and services around transit hubs. Medellín's Metrocable system stands as a notable example, successfully connecting marginalized neighborhoods with central urban areas (Xia et al., 2016) and significantly reducing travel times (Cerdá et al., 2012). However, TOD strategies can unintentionally lead to gentrification and displacement if not paired with complementary housing affordability policies (Vecchio & Martens, 2021). This highlights the necessity of cross-sectoral integration between transport, housing, and urban planning policies to ensure that improved accessibility translates into long-term inclusivity.

A critical issue in accessibility studies lies in the gap between theoretical proximity and real-world access. Pucci et al. (2019) note that even when facilities are geographically nearby, infrastructure quality, service availability, and costs often create significant barriers for vulnerable populations. To address these gaps, Paiva et al. (2022) argue for a social justice-oriented approach to accessibility, prioritizing equitable access across diverse socio-economic and demographic groups.

Measuring accessibility remains a persistent challenge, with methodologies varying significantly across studies. For instance, Ryan & Pereira (2021) and Sabella & Bezyak (2019) highlight the complexity of quantifying access deprivation, particularly for individuals with disabilities. Wong (2018) explores how social factors influence mobility among visually impaired individuals, while Boisjoly and El-Geneidy (2017) reviewed metropolitan transport plans, observing a trend towards integrating accessibility objectives. However, the practical application of accessibility-based indicators remains limited in many cities.

In terms of operational strategies, Cheng & Chen (2015) propose a multidimensional measure combining accessibility, mobility, and connectivity to evaluate public transport systems. Similarly, Guzman (Guzman et al., 2017; Guzman & Oviedo, 2018) examined 'pro-poor' public transport subsidies in Bogotá, showing how well-targeted financial measures can reduce access inequalities. Hidayati et al. (2019) report similar findings in Indonesia, underscoring the importance of context-specific policies in addressing affordability gaps.

In cities facing ageing population dynamics, accessibility becomes increasingly vital to support active ageing and continued participation in social and economic activities. Urban mobility systems must be designed to accommodate the specific needs of older adults, including considerations for safety, affordability, and physical accessibility. Initiatives integrating Smart City solutions, ICT technologies, and mobility services show promise in enhancing accessibility while addressing systemic vulnerabilities (Guida et al., 2020; Battarra et al., 2018; Pezzagno & Richiedei, 2022).

## 4.3 Mobility technologies for vulnerable groups

Technological innovations, including Mobility-as-a-Service (MaaS) platforms and AI-driven systems, hold significant potential to enhance accessibility, adaptability, and efficiency in transportation networks for vulnerable groups. MaaS platforms, such as Finland's Whim app, integrate multiple transportation modes—public transit, bike-sharing, and ride-hailing—into a single digital interface, simplifying travel planning and fare payments while offering flexible mobility options (Sen et al., 2022). Similarly, AI-powered tools enable demand-responsive transit services, optimizing routes and schedules based on real-time travel patterns and user demand, improving service availability in underserved areas (Park et al., 2022). However, despite these advancements, technological adoption remains uneven, particularly in rural and marginalized areas, where affordability, infrastructure gaps, and digital literacy barriers persist.

The limited success of MaaS in rural regions often stems from low population densities, making it economically unviable for private operators to deploy large-scale services. In contrast, urban environments with higher user volumes have seen more successful MaaS adoption, as demonstrated by Vienna's Smile app, which integrates multimodal travel and offers tailored options for elderly and disabled users. Similarly, in China (Niehaus et al., 2016) and in Singapore, AI technologies have been embedded in public transit systems to predict congestion, optimize routes, and ensure accessibility for users with limited mobility. These examples highlight the need for context-specific implementation strategies that address geographic, infrastructural, and socio-economic barriers.

For elderly individuals, technology offers both opportunities and challenges. While ICT tools can improve independence and enable real-time route planning, older adults often face digital literacy barriers and struggle with interfaces designed without their needs in mind. Moreover, outdated infrastructure—such as poorly designed bus stops, uneven sidewalks, and inadequate signage—further undermines the potential benefits of mobility technologies (Pretty et al., 2002). Research by Riazi et al. (2016) underscores these challenges, identifying outdoor navigation difficulties for visually impaired individuals, including unreadable signs, disorientation, and safety hazards.

For individuals with disabilities, paratransit services remain a critical, albeit often limited, option. Studies by Egger et al. (2022) in Switzerland highlight the barriers and facilitators affecting paratransit adoption, including poor scheduling reliability, limited coverage, and inadequate integration with broader transit networks. Addressing these issues requires infrastructure improvements alongside technological advancements, such as real-time scheduling apps and accessible payment systems, which have shown success in cities like Berlin and Zurich.

The digital divide is another significant barrier, particularly in rural areas, where access to affordable mobile devices and stable internet connections is limited. Programs like India's Common Service Centers (CSCs) demonstrate how localized ICT hubs can address digital literacy gaps, providing community-based access to digital transportation services.

Integration between technological solutions and urban planning remains a critical gap in both research and practice. Technologies like MaaS and AI-based mobility platforms are often implemented as isolated solutions rather than being embedded into broader transportation and land-use strategies. For example, while MaaS platforms in cities like Helsinki and Vienna offer flexible urban mobility options, their success relies on integrated land-use policies that ensure equitable coverage across diverse neighborhoods.

To maximize the benefits of mobility technologies for vulnerable populations, a holistic approach is essential. This includes affordable and context-specific digital solutions, inclusive design principles, infrastructure readiness, and community involvement in the design and deployment phases. Cities must not only invest in cutting-edge technologies but also ensure these systems are user-friendly, widely accessible, and tailored to the unique challenges faced by vulnerable populations.

## 4.4 Spatial and infrastructure resilience

Resilient infrastructure ensures long-term, adaptive transit networks that respond to economic, environmental, and social challenges. Initiatives like Los Angeles' electric bus fleet showcase environmental sustainability but face challenges in reaching peripheral neighborhoods (Allen & Farber, 2020).

Similarly, São Paulo's community-led BRT systems highlight how local participation can improve infrastructure relevance and adoption (Cordoba et al., 2014). Success depends on sustained investment and adaptive planning.

Recent focus on resilience in urban transportation emphasizes reducing impacts and maintaining mobility, particularly for vulnerable populations (Wan et al., 2018; Mattsson & Jenelius, 2015). Resilience is closely tied to vulnerability and has gained attention in transportation studies, especially regarding reduced mobility for the elderly and visually impaired. Muller et al. (2021) identified mobility indices for MaaS, using heat maps to evaluate accessibility and performance. Van Dülmen et al. (2022) examined transportation poverty through GPS tracking in rural Czech and German regions, finding that social disadvantage often outweighs regional differences in mobility. Compagnucci & Morettini (2020) proposed a space-equity approach for equal access to services in inner regions, emphasizing the need for integrated systems, as in rural areas (Vitale Brovarone, 2021). Universal public transportation design often neglects vulnerable users, leading to unnecessary detours and collision risks, particularly for wheelchair users (Velho, 2019), the elderly, and women with strollers. Hranický et al. (2021) addressed rail transport for people with disabilities, focusing on specialized train cars. Arai et al. (2022) used network analysis to evaluate wheelchair accessibility at train stations, highlighting proximity, reachable times, and collision risks on designated paths.

## 4.5 Technology and community engagement

Community engagement bridges policy intent with user needs, ensuring mobility solutions reflect lived experiences. Participatory initiatives, as seen in Barcelona's inclusive mobility plans and Medellín's community-driven transit projects, demonstrate how local involvement fosters trust and alignment (Comim, 2008; Cerdá, et al., 2012).

However, engagement must go beyond consultation, requiring active citizen participation in planning, monitoring, and evaluation processes.

Research by Lee et al. (2022) in South-Corea identified a strong link between life satisfaction and perceived mobility environments among wheelchair users, highlighting the importance of social initiatives to boost mobility and social interaction (Dennis et al., 2016). European policies, such as those examined by Chiscano & Darcy (2022) in Barcelona, advocate for inclusive public transport co-designed with input from people with disabilities. Technologies can also address more nuanced factors like perceptions of accessibility, safety, and communication, all of which influence mobility decisions (Sochor, 2014). Though digitization has been slow among the elderly, the increasing use of ICT and Big Data supports a shift towards green, multimodal mobility solutions (Sochor, 2015). Navigation assistance for visually impaired individuals, such as the DeepNAVI system, shows potential for promoting independent living (Kuriakose et al., 2020). However, digital solutions sometimes introduce biases that restrict accessibility for vulnerable populations, including people with disabilities (Kwakye, 2022). Common barriers include administrative restrictions, negative driver attitudes, and difficulties in securing wheelchairs in vehicles (Hezam et al., 2022; Bezyak et al., 2019). Mora et al. (2017) emphasize the importance of involving vulnerable citizens as active participants in shaping more accessible urban environments (Ferrari et al., 2014). Cities can adopt a framework that combines urban planning, mobility strategies, and governance approaches (Martinelli, 2024) to enhance urban accessibility for the elderly (D'Amico, 2024), promoting an active, inclusive, and age-friendly urban environment (Gargiulo et al., 2018).

## 4.6 Investigation of ICT solutions across regions

This section explores regional differences in the adoption and effectiveness of ICT-based mobility solutions for vulnerable groups, highlighting distinct challenges and opportunities in urban and rural contexts as identified in the literature. In urban areas, ICT tools such as Mobility-as-a-Service (MaaS) platforms, AI-powered route optimization, and digital payment systems have shown significant potential to improve accessibility and reduce mobility barriers. For example, Finland's Whim app integrates multiple transport modes into a single platform, offering flexibility and convenience (Sen et al., 2022). Similarly, Singapore employs AI-driven systems to predict congestion and optimize routes, enhancing accessibility for vulnerable users (Arai et al., 2022; Zhou et al., 2012). Research by Battarra et al. (2018) emphasizes how smart mobility technologies, when paired with inclusive urban planning, can support accessibility for the elderly and people with disabilities. However, Wong (2018) and Bezyak et al. (2019) highlight persistent challenges, including digital literacy gaps and interface design shortcomings, which often exclude older adults and visually impaired individuals. In rural regions, ICT adoption faces systemic barriers, including low population density, poor digital infrastructure, and limited financial sustainability (Combs et al., 2016; Milbourne & Kitchen, 2014). Studies by Egger et al. (2022) reveal that paratransit services, often supported by ICT scheduling tools, struggle with limited coverage and operational inefficiencies. Additionally, the digital divide remains a critical obstacle, as access to affordable mobile devices and reliable internet connections is often restricted (AbuJarour, 2022; Pezzagno & Richiedei, 2022). Cross-regional analysis reveals that affordability and user-centered design are central to the effectiveness of ICT solutions. Research by Chiscano & Darcy (2022) stresses the importance of co-creation approaches in developing accessible transport technologies, while Busco et al. (2023) argue that financial barriers often prevent low-income populations from fully benefiting from subscription-based MaaS platforms. Holistic strategies integrating ICT solutions with broader transport policies and community engagement frameworks are essential. Allen & Farber (2020) propose an accessibility-activity participation model to evaluate social inclusion outcomes, while Bantis & Haworth (2020) suggest adopting a capabilities-based approach to assess ICT interventions' impacts on equity. Additionally, Gargiulo et al. (2018) emphasize the need for smart city frameworks that prioritize social justice and ensure that technological advancements do not exacerbate existing inequalities. In conclusion, while ICT-based mobility solutions offer transformative potential, their success depends on affordable digital tools, localized infrastructure investments, inclusive design, and active community participation to address disparities across urban and rural contexts (Boisjoly & El-Geneidy, 2017; Hananel & Berechman, 2016).

## 4.7 Further research directions

Equitable and accessible transportation systems must address the physical, economic, and social barriers faced by vulnerable groups, including the elderly, disabled, and economically disadvantaged (Stanley & Stanley, 2017; Stanley et al., 2011, 2012, 2019, 2022). Infrastructure improvements, such as ramps, accessible vehicles, and ICT tools for journey planning, are essential for enhancing mobility equity. Technologies like Mobility-as-a-Service (MaaS) must be user-friendly and tailored to accommodate diverse abilities (Battarra et al., 2018).

In rural areas, where mobility barriers are more pronounced, specific investments are needed to reduce isolation and improve access to essential services such as healthcare and education (Di Ruocco, 2022a,b, 2024; Combs et al., 2016). Integration between land use planning and transport systems can minimize travel distances and improve accessibility (Lucas, 2012; Kuttler & Moraglio, 2023). Transit-Oriented Development (TOD) principles, typically urban-focused, should be adapted for rural hubs to create better connectivity.

Technological solutions, including MaaS and ICT platforms, have potential but require adaptability and scalability to overcome rural infrastructure limitations (Arai et al., 2022; Zhou et al., 2012). Additionally, digital literacy programs and affordable digital tools must accompany these solutions to bridge existing divides (AbuJarour, 2022; Bezyak et al., 2019).

Community engagement is critical for developing transport solutions that reflect local needs. Inclusive participatory planning fosters trust and aligns infrastructure with social equity goals (Chiscano & Darcy, 2022; Papa et al., 2018). Coordinated approaches involving governments, private sectors, and NGOs can ensure sustained implementation and policy alignment (Allen & Farber, 2020; Bantis & Haworth, 2020).

On this premise, this study proposes future research directions:

- Comparative Regional Analysis: Assess how urban and rural settings respond differently to MaaS and ICT adoption, focusing on factors such as infrastructure readiness, financial barriers, and cultural acceptance;
- Spatial Integration Studies: Examine how land use policies and transportation networks can be better aligned to improve accessibility across diverse geographic contexts;
- Technological Inclusivity: Investigate how digital tools can be optimized for elderly and disabled users, addressing challenges in interface design and usability;
- Affordability and Financial Models: Explore sustainable funding mechanisms, including fare subsidies and public-private partnerships, to ensure equitable access to mobility services;
- Case Study Evaluation: Deep dive into best practices from successful transport initiatives, such as Toronto’s Fair Pass program or Medellín’s Metrocable system, to identify replicable strategies (Cordoba et al., 2014; Dharmowijoyo & Joewono, 2019).

Policy Effectiveness Metrics: Develop measurable indicators to evaluate the social, economic, and environmental impacts of transport interventions in underserved areas.

# 5 Conclusions

The findings suggest that while technologies like Mobility-as-a-Service (MaaS) and ICT offer significant potential for enhancing mobility, their effectiveness is constrained without the support of well-integrated land use planning and inclusive policies (Shliselberg & Givoni, 2017). Addressing mobility poverty requires a comprehensive approach that includes technological innovations, sustainable land use strategies, and policies that promote inclusion and equity. This integrated approach will help reduce transportation disparities and improve access to essential services, particularly for vulnerable populations in both urban and rural areas. Expanding on these strategies can foster a more equitable transportation system that prioritizes social inclusion and sustainability (Pezzagno & Richiedei, 2022). However, limitations include an urban-centric focus in the literature, limited insights from rural areas, and a lack of longitudinal data to measure long-term impacts.

Despite these gaps, the study distinguishes disability-specific barriers from broader socio-economic challenges, ensuring a clear analysis of mobility inequities (Remillard et al., 2022). It highlights the need for affordable digital tools, context-specific policies, and community engagement to bridge gaps in accessibility.

Future research will refine these insights, focusing on successful case studies and developing measurable indicators for evaluating policy effectiveness. This study offers a foundation for inclusive, resilient, and equitable transportation systems, providing actionable insights for policymakers and stakeholders

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## Author’s profile

**Irina Di Ruocco**

She is a transport engineer with a degree from the University of Naples Federico II, is currently a PhD student in Methods and Models for Economic Decisions (MMED) at the University of Insubria. Her expertise includes sustainable mobility, infrastructure project evaluation, economic analysis, and European planning, particularly within EU projects. With experience in urban planning and transportation initiatives like waterfronts, ports, cycleways, and car-sharing, she has also contributed to several scientific publications in the field.