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Research paper

Electric scooters and urban CO2 reduction: A step toward greener cities*

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ABSTRACT

Electric Micromobility (EMM), encompassing e-scooters, e-bikes, and other lightweight electric vehicles, represents a pivotal shift in urban transportation toward sustainability. By addressing challenges such as traffic congestion, air pollution, and greenhouse gas emissions, EMMprovides an efficient and low-carbon alternative to traditional mobility modes. This ar ticle investigates the environmental, societal, and economic impacts of EMM, highlighting its role in reducing urban CO2 emissions by up to 40% in select cities. Real-world case studies reveal that integrating EMM with public transport can enhance first- and last-mile connectiv ity while promoting equitable access and active travel. However, widespread adoption faces challenges, including infrastructure deficits, lifecycle emissions, and regulatory inconsisten cies. To overcome these barriers, the article proposes strategies involving advanced battery technologies, modular charging solutions, IoT-enabled fleet management, and policy incen tives. By synthesizing insights from lifecycle assessments and global best practices, this study underscores the transformative potential of EMM in creating sustainable urban landscapes and achieving carbon-neutral cities

1 Introduction

The rise of electric micromobility (EMM) signifies a critical juncture in the evolution of urban transportation systems, marked by the transition from fossil-fueled vehicles to more sustainable, electric-powered alternatives. Defined by lightweight electric vehicles such as e-scooters, e-bikes, and hoverboards, EMM has gained traction in addressing the challenges posed by urbanization, congestion, air pollution, and climate change. As cities around the world grapple with achieving carbon neutrality, EMM has emerged as a promising solution, of fering efficient, cost-effective, and low-emission alternatives to traditional transportation modes (1, 2).

The shift towards EMM is not merely a technological evolution but a broader socio-economic transformation. Shared micromobility services, including dockless e-scooters and e-bikes, exemplify this transition, providing affordable and accessible mobility options that complement public transport networks. These systems cater to the growing need for first and last mile connectivity, effectively bridging gaps in urban mobility networks while reducing dependency on private vehicles (3, 4). In European cities, for instance, projections indicate that EMM could account for up to 30% of modal share by 2030, showcasing its potential to reshape transportation patterns and reduce urban congestion (2). Electric scooters have rapidly gained prominence in the urban landscape, with sales projected to exceed one million in France (5), as illustrated in Figure 1.

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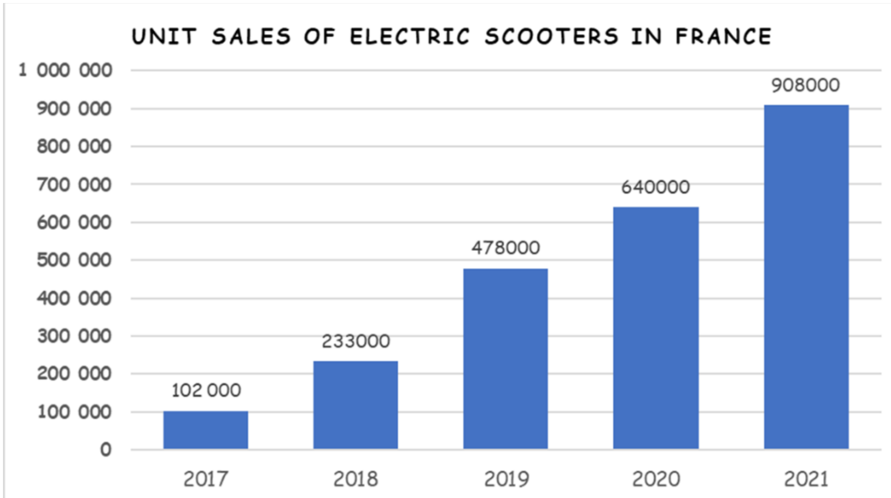

Figure 1: Global Micromobility Promotion for Electrical Scooters in France

However, the success of EMM hinges on several critical factors, including advancements in battery technologies, infrastructure development, and regulatory frameworks. At the heart of EMM lies the battery, a key determinant of the efficiency, range, and environmental impact of electric vehicles. Over the years, significant progress has been made in battery technologies, transitioning from traditional lead-acid and nickel-cadmium batteries to more advanced lithium-ion and sodium-sulfur systems (6, 7). These advancements have not only enhanced vehicle performance but also reduced lifecycle emissions, making EMM a more viable option for sustainable urban transport.

The societal implications of EMM extend beyond environmental benefits, offering eco nomic opportunities and public health advantages. By reducing vehicle ownership costs and promoting active travel, EMM fosters equitable mobility and supports healthier lifestyles (8, 7). Moreover, the widespread adoption of EMM has the potential to generate employment opportunities in sectors such as vehicle manufacturing, fleet management, and battery recycling, further bolstering its socio-economic appeal (9).

Despite its transformative potential, EMM faces significant challenges that must be ad dressed to ensure its long-term viability. These include infrastructure deficiencies, lifecycle environmental impacts, and regulatory barriers. The absence of dedicated bike lanes and inadequate charging facilities often discourages adoption, while the environmental costs associated with battery production and disposal raise sustainability concerns (10, 7). Additionally, inconsistent regulations across jurisdictions create uncertainty for operators and users alike, limiting the scalability of EMM systems.

To further understand the sustainability impacts of micromobility, lifecycle analyses (LCA) provide critical insights. For instance, the global warming potential (GWP) of different micro mobility modes reveals that while e-scooters demonstrate a significantly lower GWP compared to cars, motorbikes, and buses, only the e-scooter outperforms trains in terms of emissions. Shared micromobility modes, particularly those employing free-floating logistics, are less efficient environmentally compared to dock-sharing counterparts. Figure 2 illustrates these find ings, showing the contributions of vehicle production, distribution, and transport emissions to the GWP of each mode (11)

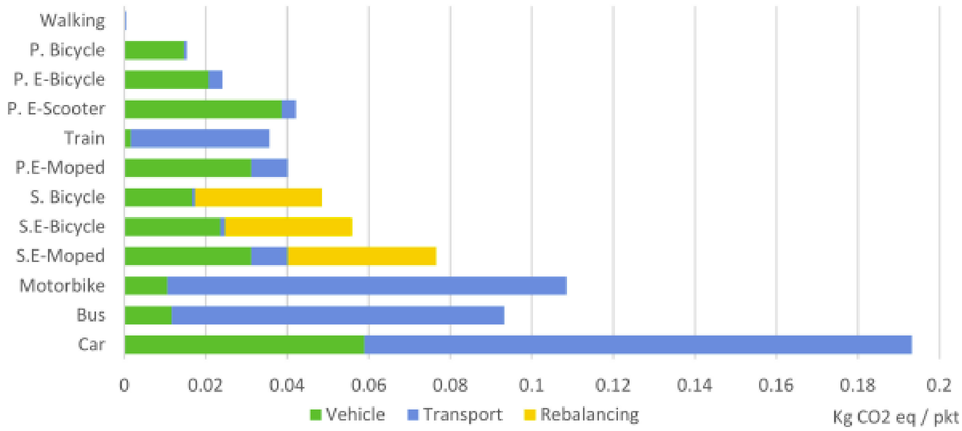

Figure 2: Global warming potential (GWP), in kg CO2 eq, for the lifecycle of various transportation modes

This article aims to provide a comprehensive analysis of EMM, exploring its benefits, challenges, and future directions. By synthesizing insights from recent research, including advancements in battery technologies and real-world case studies, it seeks to inform strategies for maximizing the impact of EMM on urban mobility and sustainability. In doing so, it underscores the need for collaborative efforts among policymakers, industry stakeholders, and researchers to unlock the full potential of EMM in shaping a greener, smarter urban future.

2. Environmental and Societal Benefits

The environmental advantages of electric micromobility (EMM) are particularly significant in addressing urban challenges such as pollution and climate change. By replacing short car trips with environmentally friendly modes like e-scooters and e-bikes, EMM systems drastically reduce greenhouse gas emissions. For instance, in Naples, Italy, the adoption of EMM led to a 12% annual reduction in CO_2 emissions, demonstrating the potential for shared micro mobility to impact urban carbon footprints positively. Similar results have been observed across six major global cities, where EMM systems achieved an average emissions reduction of 40% for trips under 5 kilometers, emphasizing their effectiveness in reducing emissions during high frequency, short-distance travel (12, 3). Beyond CO_2 reductions, EMM plays a critical role in mitigating other air pollutants, such as nitrogen oxides (NO_x) and particulate matter ($PM_{2.5}$). A case study in Zurich reported a 15% reduction in particulate emissions in high-traffic zones following the introduction of shared e-scooters, highlighting their significant contribution to improving urban air quality (9).

A closer examination of emissions reductions across cities reveals substantial variability, influenced by the integration of shared micromobility systems and regional energy policies. For example, European cities like Stockholm and Paris demonstrate notable reductions due to cleaner electricity mixes, while North American and Australian cities face challenges stemming from higher carbon intensity in electricity generation. These results underscore the need for region-specific policies to maximize the environmental benefits of EMM.

To provide a clearer picture of EMM's impact on emissions, Figure 3 presents a comparative analysis of net emissions reductions achieved by shared micromobility modes across selected cities. The data highlight the superior environmental performance of shared e-scooters, which consistently deliver higher reductions compared to shared e-bikes. These findings reaffirm the role of shared micromobility as a critical component of sustainable urban mobility strategies.

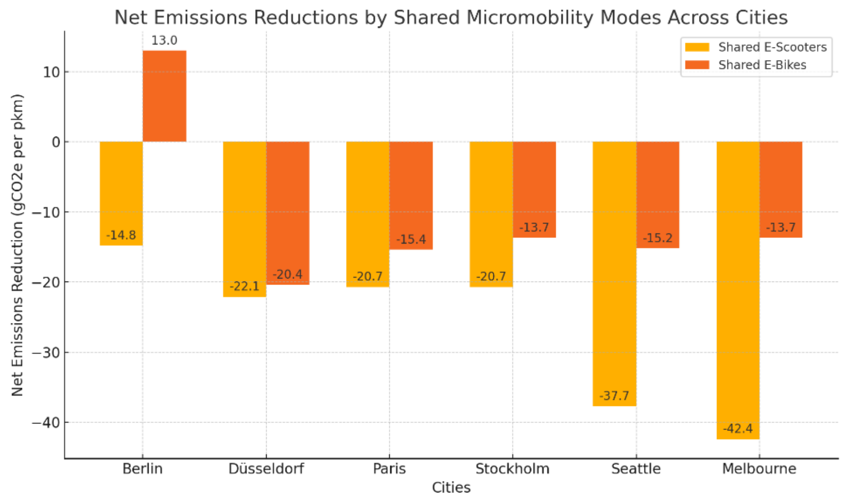

Figure 3: Net Emissions Reductions by Shared Micromobility Modes Across Cities (gCO2e per pkm). The data compare shared e-scooters and shared e-bikes in cities such as Berlin, D¨ usseldorf, Paris, Stockholm, Seattle, and Melbourne (12, 11)

From a societal perspective, EMM provides substantial benefits beyond environmental gains. Shared micromobility systems enhance accessibility and equity, particularly for underserved communities that lack access to efficient public transportation. In Taiwan, shared e scooter systems have been shown to reduce transportation costs by 50% for low-income users, making mobility more inclusive and affordable (13). Furthermore, EMM fosters active travel, contributing to improved public health outcomes. Studies in Europe indicate that the adoption of e-bikes has led to measurable declines in sedentary behavior and associated health risks such as obesity. This dual benefit of active micromobility improved health and reduced healthcare costs makes it an invaluable asset for urban planners aiming to create healthier, more livable cities (8).

The economic implications of EMM are equally significant. By reducing dependency on private vehicles, EMM lowers household transportation expenses and stimulates economic activity in sectors like vehicle manufacturing, fleet management, and battery recycling. Moreover, the integration of shared micromobility into existing urban transport systems creates opportunities for job creation and technological innovation, further enhancing its socio-economic appeal (9, 14)

3. Challenges to Adoption

Despite its numerous benefits, electric micromobility (EMM) faces significant barriers to widespread adoption. Among the most pressing challenges are infrastructure deficiencies, life cycle environmental impacts, and regulatory inconsistencies, all of which affect the scalability and sustainability of EMM systems.

A critical obstacle is the lack of dedicated bike lanes and parking facilities in many cities, which raises safety concerns and discourages potential users. For instance, studies have shown a 25% increase in EMM usage in Stockholm following the addition of 200 kilometers of dedicated bike lanes, underscoring the importance of infrastructure investments in promoting adoption (6). Similarly, inadequate charging stations for e-scooters and e-bikes remain a bottleneck in ensuring operational efficiency and user satisfaction (10).

Lifecycle environmental impacts also present substantial challenges. While EMM vehicles are known for their operational emissions reductions, the environmental costs associated with their manufacturing, maintenance, and disposal are significant. Lifecycle analyses (LCA) 4 reveal that manufacturing accounts for nearly 50% of the total greenhouse gas (GHG) emissions for shared e-scooters, primarily due to the energy-intensive processes involved in battery production (14).

To better understand these challenges, Table 1 summarizes the lifecycle emissions of various EMM vehicle types. These findings emphasize the need for sustainable manufacturing practices and efficient fleet management strategies.

Table 1. Lifecycle Emissions of EMM Vehicle Types (in kg CO2e per vehicle lifecycle). Data adapted from (15, 14, 1).

Vehicle Type	Manufacturing Phase	Operational Phase	End-of-Life Phase
E-Scooter (Shared)	70	20	5
E-Bike (Shared)	100	25	8
E-Moped	150	30	10
Personal E-Scooter	40	10	3

The data in Table 1 provides critical insights into the environmental footprint of different EMM vehicle types across their lifecycle phases. Shared e-scooters exhibit lower emissions in the manufacturing phase compared to e-bikes and e-mopeds due to their simpler designs and smaller batteries. However, operational emissions for shared e-scooters are higher than those for personal e-scooters, reflecting the additional emissions generated by fleet management activities such as charging and rebalancing. Shared e-bikes and e-mopeds, while efficient during their operational phase, incur significant emissions during the manufacturing process because of their larger batteries and more complex structures (14, 15).

Personal e-scooters demonstrate the lowest lifecycle emissions overall, largely because they avoid the emissions associated with fleet management and have smaller environmental impacts during production and disposal. The end-of-life phase contributes less to total emissions across all types, though improvements in recycling technologies could further reduce this impact. These observations underline the importance of optimizing manufacturing processes and operational logistics to minimize the lifecycle emissions of shared EMM systems.

4. Strategies for Maximizing Impact

To fully realize the potential of Electric Micromobility (EMM) in urban environments, strategic interventions in infrastructure, policy, and technology are imperative. Infrastructure development forms the backbone of successful EMM integration, with cities needing to focus on building dedicated bike lanes, strategically located charging hubs, and multimodal transport nodes. These investments not only enhance safety but also improve convenience for users. For example, cities like Stockholm have reported a 25% increase in EMM usage following the addition of 200 kilometers of bike lanes, showcasing the importance of infrastructure in fostering adoption (8). Establishing multimodal transport hubs, such as the Mobil.Punkt stations in Bremen, Germany, demonstrates how shared micromobility services can seamlessly integrate with public transport to create comprehensive urban mobility solutions (11).

Policy measures play a pivotal role in accelerating EMM adoption. Financial incentives, such as subsidies for users and tax exemptions for operators, lower barriers to entry and encourage participation. Regulatory frameworks need updates to address unique challenges posed by EMM systems, such as vehicle speed limits, parking zones, and safety standards. Addition ally, integrating EMM with public transport systems through unified payment platforms and 5 multimodal trip planning applications can enhance its attractiveness, making EMM a preferred choice for first- and last-mile connectivity (1, 14).

Technological innovations are essential for addressing environmental and operational challenges. IoT-enabled fleet management systems can optimize the deployment of vehicles, ensuring efficient operations while reducing environmental impact (16). Further, advancements in sustainable manufacturing practices, such as using recycled materials and renewable energy in production processes, can lower lifecycle emissions by up to 30% (10). These technological solutions not only improve the operational efficiency of EMM systems but also align them with broader sustainability goals.

Figure 4 provides a flowchart that demonstrates how EMM can integrate seamlessly with public transport systems. This integration involves infrastructure development, shared vehicle services, and the establishment of unified payment systems, all working together to achieve environmental and societal benefits.

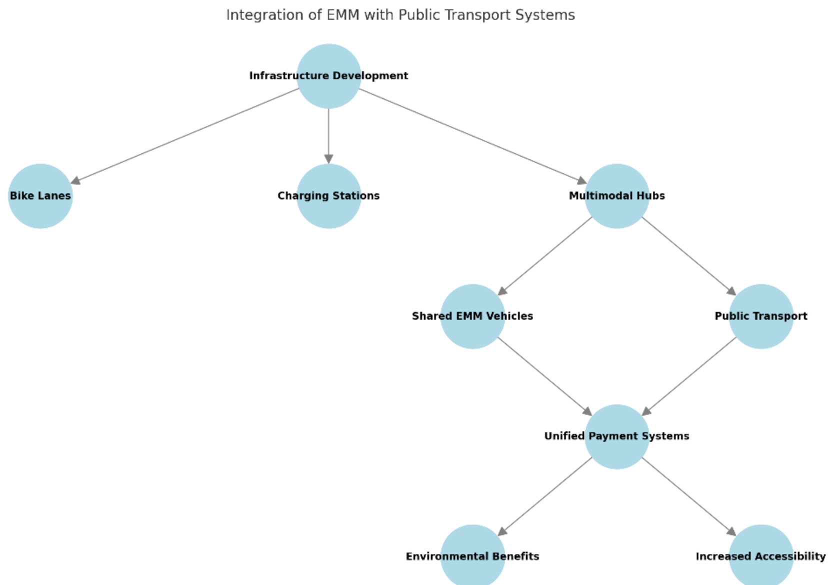

Figure 4: Integration of EMM with Public Transport Systems. The flowchart highlights the connectivity between infrastructure development, shared EMM vehicles, public transport, and the resulting benefits.

The integration of EMM with public transport can significantly enhance urban mobility, reducing environmental impacts and fostering equitable access to sustainable transportation options. These strategic interventions, when implemented collectively, have the potential to transform urban landscapes into greener, more efficient, and user-centric environments. By ad dressing challenges in infrastructure, policy, and technology, EMM can become a cornerstone of modern urban transportation systems, aligning with global sustainability goals.

Table 2: Comparative CO2 Emission Reductions Achieved by EMM Across Cities (12, 17, 15).

City	Transportation Mode Replaced	Emission Reduction (%)
Barcelona	Barcelona Car Trips	15%
Apulia	Car Round Trips	21%
Berlin	Private Vehicles	18%
Seattle	Ride-Hailing Trips	20%
Stockholm	Private Vehicles	22%
Melbourne	Private Vehicles	19%

The data presented in Table 2 highlights the significant environmental benefits achieved by Electric Micromobility (EMM) in various global cities. Barcelona's implementation of shared e-bikes led to a 15% reduction in car trips, translating to an annual decrease of approximately 8,000 tons of CO2 emissions (15). In Apulia, Italy, replacing 31% of daily car trips with micromobility solutions reduced urban CO2 emissions by 21%, showcasing the potential for significant environmental impact even in regions with high car dependency (17).

Similarly, cities like Berlin, Seattle, Stockholm, and Melbourne achieved substantial reductions in greenhouse gas emissions through the integration of shared micromobility systems. For instance, Stockholm reported a 22% reduction in emissions due to robust infrastructure investments, such as the addition of dedicated bike lanes and enhanced multimodal connectivity (12). The data underscores the superior carbon efficiency of shared e-scooters, which outperformed private vehicles and even e-bikes in terms of lightweight design and energy efficiency. The variability in emission reductions across cities can be attributed to factors such as the carbon intensity of the local energy grid, the extent of micromobility adoption, and the avail ability of supporting infrastructure. Cities with cleaner electricity generation, such as those in Europe, tend to exhibit higher reductions compared to regions reliant on coal-powered grids (18, 19). Moreover, urban policies that prioritize micromobility, such as those seen in Stock holm and Barcelona, play a crucial role in amplifying its environmental benefits. These insights emphasize the importance of tailoring EMM strategies to local contexts to maximize their impact on sustainability.

Conflicts Of Interest

The authors should pledge that they don't have any conflict of interest in regards of their research. If there are no conflict of interest then authors can declare the following "The authors declare no conflicts of interest".

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