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The Impact of Micromobility on the Environment

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Abstract

To address the growing challenges of urban traffic congestion, there is an increasing adoption of first-last mile solutions to improve accessibility. Micromobility emerges as a transformative solution for urban transportation issues, gaining recognition for its potential to reduce reliance on private vehicles for short-distance travel. This paper conducts a systematic literature review focusing on the environmental impact of micromobility across different cities. Analysing 10 articles from the past 5 years, the study reveals a nuanced understanding of the environmental footprints and potential modal shifts associated with micromobility modes, including e-scooters, electric mopeds, and bicycles. Despite short-term challenges, micromobility shows promise for fostering sustainable mobility transitions in the long run.

Keywords: Micromobility, Environment, E-scooter, Bicycle, Electric moped.

1. Introduction

In recent years, rising traffic has worsened mobility problems, especially in urban areas with high population density [1]. The first and last mile solution has emerged to address urban mobility challenges, including limited public transport accessibility and the reliance on private cars in specific urban areas [2]. The term "first-last mile" (FLM) refers to the initial and final segments of transportation journeys, but identifying these segments can be complex due to their fluid nature [1].
In the past few years, certain urban areas have embraced and actively encouraged the integration of novel forms of small electric transportation, like e-scooters and e-bikes, known as micromobility [3]. Micromobility stands as a potential solution to the myriad of transportation challenges confronting cities worldwide, offering the possibility of fostering significant shifts in transportation modes are reducing dependence on private motorized vehicles [4]. This initiative aims to enhance the accessibility and connectivity of established public transit systems. Micromobility alternatives offer a convenient and cost-effective means of complementing public transportation, bridging the gap between commuters' starting and ending points, and enhancing overall accessibility [3]. Based on the data, there is an increase in popularity and adoption of micromobility. For instance, the global proliferation of bicycle-sharing systems has been substantial, surging from 17 programs in 2005 to over 2,900 in 2019 [5]. Furthermore, e-scooter providers Lime and Bird, launched in California in 2017, achieved rapid global expansion, encompassing over 100 cities in just two years and recording millions of trips [6]. In a similar vein, the European e-scooter company VOI demonstrated comparable growth, extending its services to 10 countries within one year of its 2018 initiation in Sweden, amassing an impressive tally of 16 million rides [3]. Thus, based on this given data and the growing demand and utilization of micromobility, it is imperative to conduct further academic research in this area.
Smartphones and mobile payment systems contribute to the increasing appeal of micromobility. In contrast to docked systems that mandate rental and return at predetermined stations, dockless micromobility systems enable users to effortlessly locate available vehicles through a smartphone app. Activation of the micromobility service is conveniently achieved by scanning a QR code or using the app [7].
Based on Oeschger et al.'s [4] research, which comprehensively reviewed 48 articles until 2020 regarding the integration of micromobility and public transport, the analysis initially identified substantial gaps in the literature. While a majority of studies concentrated on discerning the motivations, preferences, and travel patterns of users combining micromobility and public transport, a noteworthy portion of the articles overlooked the examination of the broader impacts on society, the economy, and the environment resulting from this integration. Among the observed studies, only a few conducted an impact analysis, specifically quantifying potential modal shifts from private motorized vehicles to micromobility and public transport that could be anticipated with improvements to the system. A limited subset of studies explored the social impacts of enhanced integration, such as fostering social inclusion, reducing disparities among different population groups, and expanding access to services and opportunities. However, none of the 48 selected articles included a comprehensive quantification of the potential impacts of effective integration of micromobility and public transport on the environment, liveability, sustainability, and the economy [4].

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Two research gaps have been identified, and this paper aims to address them by presenting current knowledge on the environmental impact of various micromobility modes, particularly focusing on carbon dioxide emissions throughout the vehicle's life cycle.

2. Micromobility and public transport integration

Micromobility holds the promise of addressing the drawbacks of the current automobile-centric transportation system. Additionally, it is anticipated to enhance the quality of public transportation services by effectively resolving the first-last mile challenge, a commonly identified limitation in the current public transportation system. Acting as a viable alternative, micromobility can bridge the gap between the initial and final miles, offering a solution to alleviate traffic congestion and minimize environmental impact [8], [9], [10], [4], [11]. To comprehensively evaluate the environmental impact of micromobility, it is essential to categorize the various modes of micromobility (Fig. 1). Micromobility is characterized by the utilization of micro-vehicles, which are defined as vehicles with a maximum speed not exceeding 45 km/h and a mass not surpassing 350 kg. These vehicles can be electric, electrically-assisted, or human-powered. Predominantly employed for transportation in urban settings, the most prevalent micro-vehicles include bicycles, e-bikes, and scooters [12].

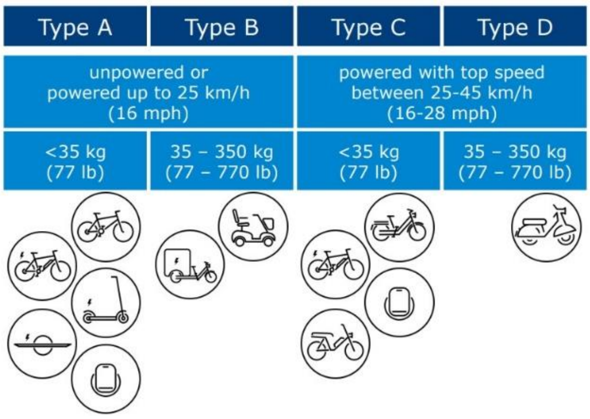

Fig. 1. Micromobility definition and classification [12].

Kagel et al.'s [13] research on the bicycle–train combination and the integration of micromobility and public transport reveals a common thread of synergy in creating efficient and sustainable transport systems. In the case of the bicycle–train combination, the melding of the bicycle's flexibility and the train's speed results in an integrated transport system suitable for various distances, offering increased adaptability to individual demand and urban and regional conditions. Cycling excels for short distances, while trains, representing high-speed transit, shine for longer distances, forming a 'wormhole' capability for connecting urban areas farther apart.

The seamless integration of micromobility with public transport presents a spectrum of approaches contingent upon the existing infrastructure and services within a given location. Within the realm of micromobility, both shared and private micro-vehicles play pivotal roles, with shared systems experiencing a surge in global popularity. These systems, classified as either station-based or dockless, have evolved into efficient and user-friendly alternatives, particularly for first and last-mile connectivity to public transport [4]. Station-based systems, by design, confine trips to predefined locations, while their dockless counterparts provide a more flexible range of starting and ending points. However, the latter approach prompts cities to grapple with challenges related to parking in specified zones. The success of micromobility and public transport integration hinges on the type of micro-vehicle employed—whether private or shared. Private micro-vehicles, exemplified by bicycles, often necessitate storage at both trip ends. In contrast, shared vehicles require not only readily available options but also designated parking areas to optimize their functionality [4].

The integration not only offers a variety of options for first and last-mile journeys but also provides the flexibility to combine these options based on the availability of services and infrastructure. For instance, a first-mile trip using private micro-vehicles can seamlessly dovetail with a last-mile journey utilizing shared micro-vehicles from docking stations, free-floating dockless shared micro-vehicles, or even walking. This adaptability underscores the dynamic nature of micromobility practices in enhancing overall connectivity within the broader transportation network [4].

To facilitate a comprehensive understanding of the environmental aspects related to micromobility and the existing research landscape, this paper conducts a systematic literature review. The primary focus is on exploring the impact of various micromobility modes on the environment.

3. The systematic literature review (SLR) approach

A systematic literature review was undertaken to assess the current understanding of the environmental impact of integrating micromobility with public transport. This study aims to ascertain the existing knowledge concerning the environmental effects of the integration of public transport and micromobility, identifying specific evidence of their impact on the environment. The methodology employed for this systematic literature review was crafted and adjusted in accordance with the guidelines outlined by Thomas and Harden [14].

In the first step, the research goal and strategy were defined, including a clear and methodically documented definition of search terms and combinations of those terms in search strings, identification of databases to be used, filters, and inclusion and exclusion criteria on which to base the search and selection processes. The research question that is at the core of this study is: what is the impact micro mobility on the environment? Not that much research has been done in this field [4]. This question encompasses another question that what recommendations have been made until now? In general, the aim of this literature review is to investigate the results and recommendations presented in the literature review as of November 2023.

The literature search was conducted in the Scopus database under "titles, keywords, or abstracts" utilising peer-reviewed articles primarily focused on the past five years with similar keywords.

Relevant information was extracted and documented for each article such as the type of micro-vehicle, method types used and the city or country that the study focuses on. The 10 articles were selected for this systematic literature review. The articles were divided into two groups based on the used method: 1) Life Cycle Analysis (LCA) of micro-vehicle, and 2) traffic simulation and modelling. Following this classification, for each study the type of micromobility examined and the case study area (city/region) were documented.

The Life Cycle Assessment (LCA) is widely recognized as the predominant standardized approach for evaluating the environmental impacts of a product across its entire life cycle [15]. For analysing in this section, we are going to consider each moved separately and gather the result from our 10 articles. The findings of this research culminated in Table 1 and is further described in the next section.

Table 1. Articles that focus on the environmental impact of micromobility.

	Reference	Mode of transportation	City / Country	Method type	Year	Number of citations	Keywords
1	De Bortoli [16]	Bikes, second-generation e-scooters, and e-mopeds	Paris	Life cycle assessment (LCA) method	2021	52	Environmental performance; Shared mobility; Micromobility; Bike; E-scooter; Moped
2	Reck et al. [17]	E-scooter, e-bike	Zurich	Traffic analysis, modelling (mode choice)	2022	103	E-scooters; E-bikes; Micro-mobility; Competition; Mode choice; Environmental impact
3	Felipe-Falgas et al. [18]	Shared Electric and Mechanical Bicycle	Barcelona	Life cycle assessment (LCA) method	2022	14	Micromobility; shared mobility; modal change; life cycle assessment; environmental performance; greenhouse gas emissions; public health; two-wheeled vehicles
4	Fan & Harper [19]	Micromobility	Seattle	Data analysis and traffic simulation method	2022	26	Micromobility; travel demand; model congestion; emissions; energy use;
5	Hollingsworth et al. [20]	Shared dockless electric scooters	United state	Life cycle assessment (LCA) (using Monte Carlo simulation method for distribution)	2019	380	Electric scooter, life cycle assessment, transportation, environmental impacts
6	Moreau et al. [21]	Shared dockless standing e-scooter	Brussels	Life cycle assessment (LCA) method	2020	106	E-scooter; life cycle assessment; product-service system; environmental assessment; mobility
7	Severengiz et al. [22]	Shared e-scooter	Bochum, Germany	Life cycle assessment (LCA) method	2020	18	Novel mobility services; environmental impact; light electric vehicles; e-scooters; life cycle assessment; electric mobility
8	Schelte et al. [23]	Electric Moped Scooter sharing	—	Life cycle assessment (LCA) method	2021	18	Shared mobility; electric moped scooter; life cycle assessment
9	Montes et al. [24]	Shared micromobility	Rotterdam	Discrete choice modelling techniques	2023	1	Choice modelling; Mode choice; Public transport; Shared micromobility; Stated choice
10	D'Almeida et al. [25]	Bike sharing system	Edinburgh	Life cycle assessment (LCA) method	2021	27	Mobility; Bike sharing schemes; Carbon emissions; Life cycle analysis; Rebalancing operations

4. Results And Discussion

Within this segment, a detailed exploration is undertaken to assess the environmental ramifications of diverse micromobility modes, considering both lifecycle perspectives and simulation models. The outcomes of this analysis are systematically categorized into three primary sections, each dedicated to a specific micromobility mode: E-scooter, Bicycle, and Electric moped. Through this structured approach, a nuanced understanding of the ecological footprint of each mode emerges, laying the groundwork for a comprehensive examination in subsequent sections.

4.1 E-scooter

E-scooters have become a popular choice, often substituting walking or biking (49%), personal cars or ride-shares (34%), and even public buses (11%) [20]. The transition to e-scooters, however, introduces its own set of environmental considerations.

Choosing e-scooters over personal cars universally contributes to a decrease in the impact of global warming, according to Hollingsworth et al. They recommend strategies like extending scooter lifetimes, reducing collection and distribution distances, using more efficient vehicles, and adopting less frequent charging to mitigate environmental impacts. Failure to implement these measures could result in a net increase in global warming impact in 65% of simulations [20].

Additionally, according to the study by Severengiz et al., utilizing e-scooter sharing in this scenario, where the use of e-scooter sharing leads to an increase in public transport usage, proves effective in addressing certain issues, particularly in reducing the demand for parking [22].

However, as explained in the De Bortrali report, both entry-level and mid-range models of shared e-scooters, along with private e-scooters, exhibit a higher carbon footprint than alternative modes. De Bortoli's findings underscore that shared e-scooters, depending on their lifespan, bear the highest carbon footprint compared to shared e-mopeds and shared bicycles [16].

Based on a global warming perspective, dockless e-scooters need a lifespan of at least 9.5 months to be a green solution for mobility in the current use situation. Additionally, they prove that the potential environmental impacts from the dockless e-scooter usage in Brussels are higher than those of the modes of transportation they replace or in comparison to the use of the personal e-scooters [21].

Felipe-Falgas et al. delved into a comparison of the carbon footprints of personal e-scooters with shared e-bicycles and shared e-mopeds. While personal e-scooters emerge as one of the less harmful options in terms of CO_2 equivalent, the study underscores the complexities of comparing shared and personal micromobility, emphasizing that shared service logistics contribute significantly to CO_2 emissions [18].

The result shows that co2 emission of personal e-scooters (42 g CO_2 / pkm) is lower than the average CO_2 emissions of the modes it replaces (58 g CO_2 / pkm). While shared e-scooters exhibit the opposite pattern: the CO_2 emissions is higher than the average CO_2 emissions of the modes they replace [17].

4.2 Electric Moped

In terms of CO_2 equivalent emissions, the shared electric moped emerged as the most environmentally taxing among the four micromobility modes investigated [18].

The study discloses that shared e-mopeds display a greenhouse gas warming potential (GWP) ranging from 20 to 58 g CO_2-eq. / pkm. The optimal scenario, involving solar charging and electric van battery swapping, contrasts with the least favourable scenario, which assumes a shorter lifespan, diesel van swapping, and charging with the German electricity mix. The operational logistics, particularly during the use phase, significantly influence GWP [23].

Comparisons with previous studies indicate that, with extended lifetimes and efficient operations, e-moped sharing can rival public transport in terms of GWP. The research advocates strategies such as minimizing the environmental impact of aluminium in production, incorporating renewable energy sources, optimizing e-moped design for durability, and encouraging battery reuse [23].

4.3 Bicycle

The private bike stands out as the most efficient mode across ecosystem damage, climate change, primary energy, resource damage, and human health damage. It surpasses shared bikes in three damage types but ties with shared e-scooters in carbon footprint and mid-range private e-scooters in primary energy consumption [16].

De Bortoli's study reveals that private steel bikes have the lowest carbon footprint among all micromobility options, followed by private aluminium bikes and shared bicycles. The shared bike, while ranking higher in carbon footprint due to shorter lifetime mileage and the impact of bike-sharing stations and servicing, still fares better than shared e-mopeds, which in turn outperform shared e-scooters [16].

In Seattle, an examination of emissions from charging and rebalancing shared e-bikes in comparison to driving a car for equivalent trips reveals noteworthy environmental implications. At the highest penetration rate of 18%, a shift to micromobility modes from short car trips could potentially yield a significant 2% reduction in light-duty transportation emissions and energy consumption. This equates to a reduction of 5 tons of carbon dioxide (CO_2) and 73 Giga Joules (GJ) per workday, particularly during the peak hours of 3-4 PM. Extrapolating this reduction over a full year, considering 220 workdays in a calendar year, amounts to a substantial decrease of 1,130 tons of CO_2 and 16,124 GJ annually [19]. In this scenario, shared e-bikes, operating at the upper bound penetration rate, contribute to a remarkably lower environmental impact, producing only 0.15 metric tons of CO_2. In contrast, traditional light-duty vehicles generate a significantly higher 5.29 metric tons of CO_2 for the same trips. This underscores the potential environmental benefits of transitioning to shared e-bikes, particularly in the context of urban transportation in Seattle [19].

In D'Almeida et al.'s paper, the environmental impact of a public self-service bike sharing system in Edinburgh is assessed through an LCA. The study emphasizes the role of such systems in reducing carbon dioxide equivalent emissions compared to previous transportation modes. The key findings underscore the importance of optimizing rebalancing operations and manufacturing bikes closer to the point of use for further emission reduction. The study identifies the use phase as a crucial variable and explores several factors, providing insights for authorities considering bike sharing systems as a greenhouse gas reduction intervention [25].

In Zurich, micro-mobility modes primarily serve as substitutes for walking during short trips, with increasing proportions replacing public transport, bikes, and cars as distances lengthen. Notably, personal e-bikes emerge as particularly effective replacements for personal cars over longer distances when compared to other modes [17]. Moreover, the result shows that co2 emission of personal e-bike (34 g CO_2 / pkm) is lower than the average co2 emission of the mode that it replaced (88 g CO_2 / pkm). While shared e-bike shows opposite pattern [17]. Despite the potential short-term increase in CO_2 emissions associated with shared e-bikes and e-scooters, there is optimism regarding their role in fostering sustainable mobility transitions in the long run, especially if usage eventually translates into ownership [17].

5. Conclusion

In this paper, a systematic literature review was conducted, to determine how the environmental impact of micromobility has been studied to date. Through a systematic approach, 10 articles have been selected and analysed in this study, that specially focused on subject of micromobility and environmental impact of different micromobility modes. The main goal was to identify the aspects of the topic that have been empirically examined to date, while also discovering the results and recommendations presented. In a second step, the main recommendation and result from 10 articles were collected and organized into categories, in order to underline the main issues. While micromobility modes exhibit minimal direct emissions during urban vehicle use compared to fossil-powered vehicles, shared services reveal slightly elevated emissions, primarily attributed to fleet rebalancing activities. This outcome stands as a significant gap, challenging the prevailing belief that sharing is universally environmentally beneficial. The environmental analysis of micromobility modes underscores their varied footprints, with shared e-bikes and personal e-bikes showing potential as eco-friendly alternatives. The findings emphasize the importance of considering factors like lifespan, logistics, and operational efficiency in evaluating the environmental impact of micromobility. Despite challenges, the study remains optimistic about the role shared micromobility provides in fostering sustainable mobility transitions, urging further research and policy initiatives to fully realize its potential benefits.

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