Conceptualizing Micromobility

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Article

Conceptualising Micromobility: The Multi-Dimensional and Socio-Technical Perspective

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Abstract: Micromobility has gained attention from policymakers, industry stakeholders, and academia; however, a comprehensive conceptualization of micromobility is still missing. Existing definitions are largely vehicle-centric: either listing modes or detailing vehicle characteristics. This paper addresses this gap by developing a 'beyond vehicles', multi-dimensional conceptualization of micromobility, accompanied by a novel socio-technical definition. Through a review of related concepts, combined with an analysis of the use and definitions of the term micromobility in publications, this study establishes a new conceptualization of micromobility. It incorporates human, social, and cultural dimensions, considers environmental, economic, infrastructure, vehicle technology, regulatory and policy aspects, and considerations for public health. Our definition of micromobility encompasses a wide range of mobility options typically used for shorter trips and manoeuvrable by an individual without motor assistance, at least for short distances. These modes are characterized by their 'micro' attributes, including low energy demand, environmental impact, and road space use relative to automobility. The conceptualization incorporates a range of micromobility modes, including fully human-powered (including walking), partially motor-assisted, and fully powered options. These modes typically operate at speeds not exceeding 25 to 32 kilometres per hour (or 45 km/h for faster options), weigh (typically substantially) below 350 kilograms and often yield significant (public) health benefits. Trip length is generally less than 15 kilometres, and daily distances under 80 kilometres. Importantly, our definition includes the practices, policies, cultures, and infrastructures that emerge around the use of micromobility options and shape their uptake. This proposed conceptualization significantly broadens the prevailing vehicle-focus in micromobility debates towards a socio-technical perspective. Embracing a widely accepted conceptualisation of micromobility would offer several advantages, including robust design standards, legislation, and evaluation metrics and methods. Additionally, this paper highlights the pivotal role micromobilities can play in transcending the limitations of automobility, towards more sustainable and equitable mobility futures.

Keywords: micromobility; sustainable transport; electric vehicles; active travel; LEV; socio-technical analysis

1. Introduction

Globally, micromobility could be more important than electric cars in reducing transport's stubbornly high carbon emissions (IEA, 2021). It also brings positive social and economic benefits aligned with a range of Sustainable Development Goals (United Nations, 2015). It could thus play a

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central role in transitioning to lower carbon mobility (Moradi & Vagnoni, 2018). Despite this significance, the term micromobility is not well conceptualised in the academic literature.

Industry analyst Dediu (Micromobility, 2017) is widely credited for coining the term micromobility in 2017. The term has gained currency very quickly over the last few years, in policy, industry and academic contexts, with multiple definitions and understandings of the term. However, a detailed conceptualization and broadly accepted definition are still missing. The emerging body of literature on micromobility is largely based on empirical studies and definitions of the term are typically short, usually limited to listing a range of micromobility modes, or a focus on weight and speed characteristics (see section 3). Debates closely related to micromobility (see section 2) tend to be only weakly linked with considerations of the term micromobility. This paper addresses these gaps and proposes a new conceptualisation of micromobility that goes beyond vehicle -based definitions to provide a broad socio-technical approach and multi-dimensional understanding of micromobility. which, controversially, includes walking (sections 4 and 5).

Some of the mobilities commonly understood as micromobility, such as shared electric scooters, are a relatively new additions to our cities and have been adopted fast in some countries. Other modes, such as bicycles have been around over two centuries, having gone through phases of mass-scale uptake, followed by decades of marginalization before the recent phase of popularity and further technical development (e.g. e-bikes). This means that, while the term micromobility may be new, many modes that may be considered ‘micromobility’ - such as walking, cycling or use of scooters - have long and rich histories of policy, industry, and academic debate (Ploeger and Oldenziel, 2020; Dekker, 2021).

While some modes typically understood as micromobility (e.g. cargo bicycles) have been marginalized because they did not ‘fit in’ to mainstream categories (see e.g. Cox, 2012), others (such as wheelchairs or mobility scooters) are largely absent from the debate because they largely serve particular groups, or because they are mainly only popular in the ‘Global South’ (such as Tuk-tuks, Boda Bodas).

Walking is rarely discussed as constituting micromobility. As this paper follows a socio-technical approach, or a ‘beyond vehicle’ perspective – integrating technologies with social practices – we argue for integrating pedestrianism. Walking is also ‘micro’ in terms of environmental impact and land use, while being a central mode for most people. Including walking could provide new alliances within transport debates (see section 2) and strengthen the argument towards post-automobile low-carbon mobility futures across the globe. Globally, and historically, walking is central to most people’s mobilities. Even drivers and air travellers cannot reach their cars or planes without walking to them.

The (re-)emergence of micromobility comes with many contestations, for example around safety, road space and legislation. Conflicts between pedestrians and shared e-scooters are one example. Policy makers often scramble to provide frameworks within the dominant (auto)mobility frameworks, like allocating small amounts of space, often creating conflict with other micromobility modes such as walking or cycling. More radical approaches re-allocate automobile infrastructure, with an acceleration during Covid-19 in some places. Overall, the legal frameworks for micromobility vary, and are changing rapidly.

Our conceptual approach to micromobility is informed by a mobility studies perspective, seeking “to address entire mobility systems, logistical practices, energy cultures, and the way everyday practices are embedded in these larger socio-technical systems” (Sheller, 2018a, p. xv). We take a socio-technical perspective where systems such as mobility “consist of a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks” (Geels, 2005). This paper’s main research question is thus: How can we best conceptualise micromobility in a socio-technical and multi-dimensional manner? To answer this question, the paper reviews micromobility-related concepts (section 2), analyses the emergence and use of the term micromobility in the academic literature (section 3), proposes a socio-technical conceptualisation of micromobility with seven dimensions (section 4), and contributes a new micromobility definition (section 5), followed by the conclusion (section 6).

2. Micromobility-related concepts

This section reviews concepts that are closely related to micromobility: active travel, non-motorised transport, powered two-wheelers, electric mobility, Light Electric Vehicles (LEVs), multi-modal transport, shared mobility/Mobility as a Service (MaaS), and smart mobility. They were selected based on the expertise of the co-authors and in consultation with senior scholars. While there are tensions between (elements of) some of these concepts, we mainly focus on potential synergies. The limited amount of interaction between many of these concepts (e.g. between active mobility and LEVs, or non-motorised transport and electric mobility) results in research, innovation and policy in rather siloed ways. Similarly, whilst the term micromobility may facilitate debates across these concepts, the current lack of a broadly accepted conceptualisation and definition exacerbates confusion and causes misalignment across agendas. Our definition of micromobility, with its dimensions and characteristics (see sections 4 and 5), builds on this section's concepts and intersections between them, thus embedding micromobility within a broad set of literature, disciplines and policy agendas.

2.1. Active Travel

The term 'Active travel' (or mobility/transport) comes from the public health field and covers modes that require some physical activity, such as walking and cycling. More recently, active mobility debates have started to include assisted modes such as electrically-assisted cycling (Sundfør et al., 2020). The 'active' element of other modes of micromobility (such as e-scooters), where users stand up rather than sitting down and push off to get started, is less explored in the literature. Significantly, one major mode of active travel, walking, is typically not included in micromobility definitions and debates. Instead, tensions are often described, e.g. between pedestrians and e-scooters (Fitt & Curl, 2020).

Most active modes tend to be considered as micromobility, depending on definitions (see below). Yet, micromobility can also include modes excluded from active travel, such as electric mopeds. Nevertheless, the physical activity and associated public health dimension are key for considering the societal and individual relevance of (specific modes of) micromobility, while it is important to keep tensions, alliances and synergies between walking and (other) micromobilities in mind.

2.2. Non-motorised Transport

The concept 'non-motorised' transport/mobility comes from the transport field and has been around since the 1970s. It has some overlap with 'active' debates, e.g. in terms of focusing on walking and cycling – and is often used to group these modes for modelling purposes. It is a key concept used by organisations, especially those focussed on the Global South, such as the UN (United Nations Environment Programme, 2019). The term is complicated by the emergence of electrically-assisted modes such as e-bikes that are partially human-powered and (optionally) partially powered by an electric motor. It would be interesting to explore how a micromobility grouping in transport modelling could provide new insight into potentially achieving low-carbon futures. IPCC reports indicate the high feasibility of non-motorized transport as an important mitigation and adaptation option for climate change (de Coninck et al., 2018, pp. 16–17). This underlines the importance of linking micromobility debates with those on non-motorized transport and strengthens the argument for including walking in a definition of micromobility.

2.3. Powered Two-wheelers

The debate on powered two wheelers (PTWs) – motorcycles, mopeds and scooters –is of particular importance for the Global South, where they are the most prevalent vehicle type in several low- and middle-income countries (Gutierrez & Mohan, 2020). Related accidents fatalities are high, making safety research a particularly strong focus (O'Hern & Estgfaeller, 2020). PTWs are often used for transportation of passengers and goods, both in dense urban areas and in rural off-road contexts, increasingly facilitated by mobile phone services. Moped and scooter type PTWs fall under most understandings of micromobility, and provide an important Global South perspective, yet links

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between both debates remain scarce. Within debates on e-mobility in the Global South, electric two-wheelers are often identified as the most promising vehicle type (Rajper & Albrecht, 2020), confirmed by current market growth.

2.4. Electric Mobility

As many of today's micromobility modes are (sometimes optionally) powered by an electric motor, wider debates on electric mobility are also relevant to micromobility. Electric mobility is often conceptualised narrowly in terms of electric cars (Behrendt, 2018). Mapping the interactions between electric modes – whether 'micro' or otherwise (see definition below) – is an important prerequisite for broadening and accelerating the electric mobility agenda. A switch to electric cars is also often regarded as the main route to reaching climate targets without re-thinking automobility – a strategy which is likely to be insufficient (Henderson, 2020). Instead, a broader, micromobility-inclusive understanding of electric mobility would have a better chance of achieving carbon reduction goals.

2.5. Light Electric Vehicles (LEVs)

The term Light Electric Vehicles (LEVs) covers many of the mobilities that fall under the umbrella of micromobility, e.g. “electric bicycles, 3- and 4-wheelers, skateboards and segways” (Hyvönen, Repo and Lammi, 2016, p. 258).Others define LEVs as vehicles that fall within the UNECE's M1-category (Ewert et al., 2020) or the EC's L (European Commission, 2022) with specific attributes and categories. These varying LEV definitions do not cover fully human-powered vehicles such as bicycles or practices such as walking, and some do include quite heavy vehicles. Adoption is uneven globally, with “considerable market share in Asia, [while] LEV sales in Europe are still very low” and research with a global perspective very much missing (Ewert et al., 2020, p.2) while “outdated” and “inaccurate” regulations are currently a bottleneck (LEVA-EU, 2022) – concerns that both LEV and micromobility advocates share.

2.6. Multi-modal transport

Micromobility options, particularly shared e-bike and e-scooter schemes, are often used as access or egress options for modes such as public transport (Oeschger et al., 2020). Multi-modal transport research, especially with a focus on integrating with active modes, is key for micromobility. The ‘first and last mile’ distance traditionally covered by walking and cycling can be extended by other micromobility options, or made available to the less mobile. It diversifies public transport opportunities. Micromobility definitions, research and policies would therefore benefit from including multi-modal elements, particularly those that integrate with public transport. Similarly, multi-modal and public transport debates would benefit from closer consideration of micromobility.

2.7. Shared Mobility and Mobility as a Service

Some forms of micromobility are increasingly available as shared schemes, especially bicycles and e-scooters (docked and dockless). For this paper's multidimensional approach to micromobility, equity questions (Dill & McNeil, 2021) from the shared mobility literature are especially relevant, for example, how to understand actual and potential users, who do or do not have access to these modes and why, and what conflicts over public space and parking emerge (Petzer et al., 2020). Mobility as a Service (MaaS), where (one or several) shared modes are made available via an app, including services such as wayfinding, booking, unlocking, etc. (Hensher & Mulley, 2020; Lyons et al., 2019) may or may not include micromobility. Unintended consequences of MaaS, such as further social exclusion and focus on monetary rather than social goals (Pangbourne et al., 2020) are also potentially relevant to micromobility discussions.

2.8. Smart Mobility

Many forms of micromobility include some digital/data element, especially shared schemes. The concept of smart mobility almost by definition involves the use of Information and Communication Technology (ICT) in mobility/transport, often in the context of smart cities. Emerging literature considers how to best approach the data elements of shared mobility (Fischer, 2020; Shaheen & Cohen, 2019; Transportation for America, 2020) and MaaS (Cottrill, 2020). This scholarship interrogates smart mobility's knowledge claims and assesses how value is extracted and what issues arise around surveillance and privacy (Behrendt & Sheller, 2022; Petersen, 2019; Spinney & Lin, 2018). Studies of smart mobility sometimes draw on micromobility case studies (van Oers et al., 2020). Overall, discussion and governance of smart mobility is largely automobility focussed, with some consideration for public transport, but little regard for micromobility.

This critical discussion of eight micromobility-related debates has identified elements of each debate that are highly relevant to our socio-technical understanding of micromobility but have so far not been systematically integrated in the micromobility literature. The review of these debates has also identified potential for collaboration and synergy that can strengthen scholarship as well as policy debates around micromobility, beyond siloed perspectives.

3. Use and Definitions of the term Micromobility

While the micromobility-related concepts discussed above provide broader socio-technical context, this section shows specifically how the term 'micromobility' itself has been employed and defined in the academic literature and compares the two non-academic definitions that are frequently used.

3.1. Incidences and trends

We searched Scopus with the following keywords: (1) 'micromobility', (2) 'e-scooters', (3) 'e-bike OR e-bicycle', and 'shared AND bicycle OR bike', until the end of 2022[1]. Figure 1 shows the prevalence of these words in scientific papers in the (a) title, as well as in the (b) title, abstract and keywords.

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[1] We used the following search strings:
1. *TITLE-ABS-KEY (micromobility) ; 2. TITLE-ABS-KEY (shared AND bicycle OR bike) ; 3. TITLE-ABS-KEY (e-bike OR e-bicycle) ; 4. TITLE-ABS-KEY (micromobility) ; 5. TITLE-ABS-KEY (e-scooters); 6. TITLE (micromobility) ; 7. TITLE (shared AND bicycle OR bike) ; 8. TITLE (e-bike OR e-bicycle) ; 9. TITLE (micromobility) ; 10. TITLE (e-scooters)*

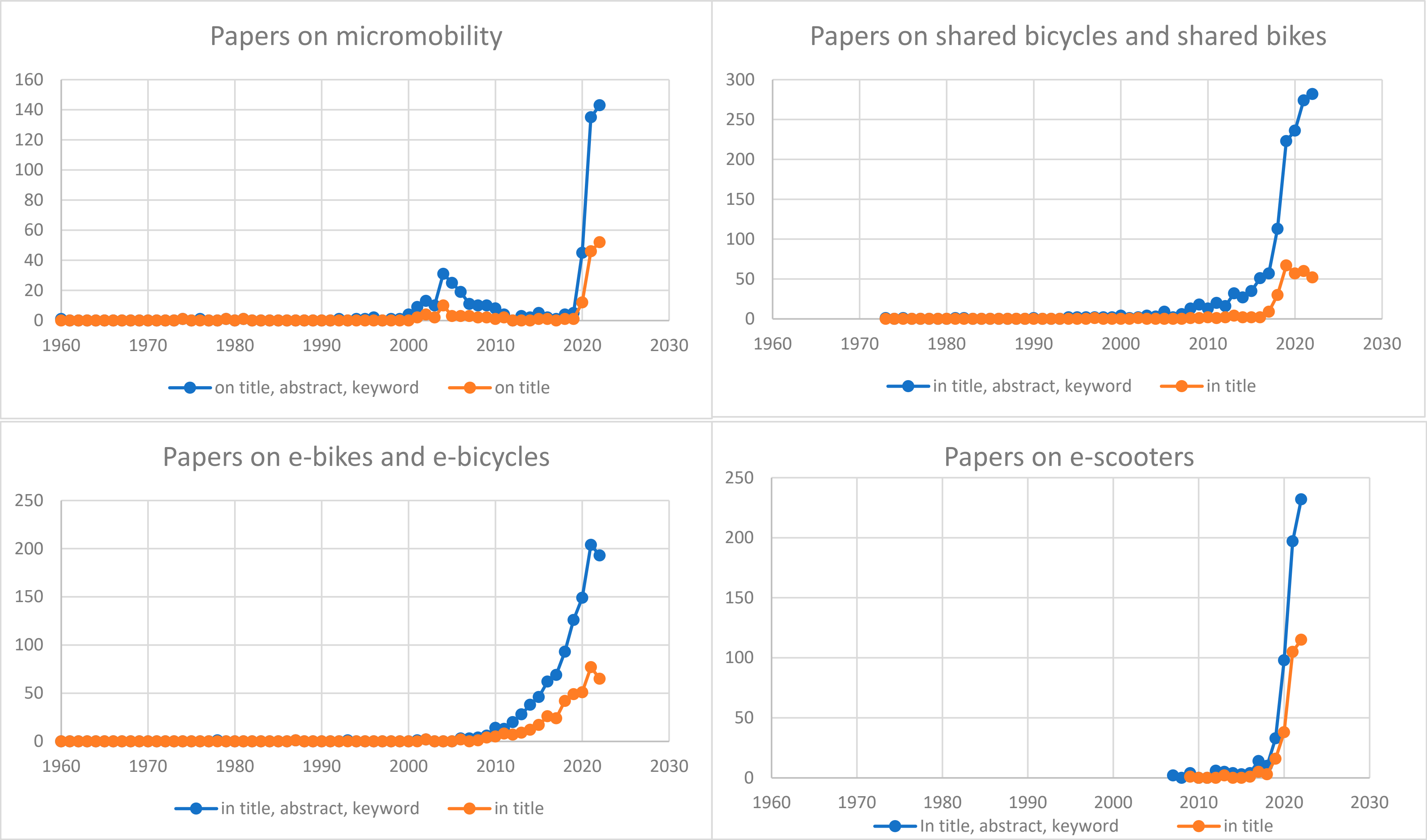

Figure 1. The prevalence of terminology in title, abstract and keywords, and title only.

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The results show that the term 'micromobility' is mentioned 151 times in the title, and 510 times in the title, abstract, and keywords. A sharp rise in academic papers took place in recent years: from 2015 to 2019, 0 to 1 paper(s) with micromobility in the title were published annually, whilst in 2020 this rose to 12, in 2021 to 46, and in 2022 to 52. There is a similar increase for papers that used the term in their keywords and abstract. An earlier peak of the term (2004) was not transport related. Most papers during that period focussed on wireless (tele)communication.

A large increase in the number of published papers can also be observed for modes that are often associated with micromobility, such as e-scooters and e-bikes. The attention to e-bikes, shared bikes and e-scooters has so far prevailed over the specific term 'micromobility', and, in the case of e-bikes and shared bicycles has risen over a longer time, respectively, since about 2010 and 2015.

3.2. Use and definition of micromobility

Next, we focus on how the term 'micromobility' is used and defined in the scientific papers identified above. The search is limited to papers with micromobility in the title, rather than keywords or abstract, on the basis that such articles were likely to have a stronger focus on micromobility. Out of the 151 identified papers, this analysis only considers publications in journals, in English, and for the transport context, and excludes one publication that we could not access, resulting in 60 documents (see Tables 1 & 2).[2] We then extracted data from the included studies regarding the studied location, whether a definition of Micromobility was provided, and if so, what the definition was. We also summarized the focus of the paper in terms of mode considered, the type of paper (e.g. review, empirical, case study) and the topic of the paper (see Table 2). Three authors were involved in the process and each screening step was conducted by at least two authors to reduce bias in screening and quality assessment. Table X gives the full bibliographical detail of the 60 papers included in the analysis.

Table 1 provides an overview of the definitions used in these 60 documents. Interestingly, more than half of the papers did not provide any clear definitions of micromobility. Those that explicitly offered a definition were often based on definitions by the International Transport Forum (ITF) and the Society of Automotive Engineers (SAE), but also sometimes based on Wikipedia, a website, or a provider of audit and assurance (Deloitte). Other papers operationalize the term but do not provide a clear definition. The absence of a broadly agreed definition of micromobility in the scientific literature has therefore resulted in variations of the use of the term and a subsequent lack of clarity and inconsistency in what is or is not included.

Several of the papers provide examples of micromobility, most often bicycles, e-bikes and e-scooters. Indeed, Table 2 shows that the majority of papers with micromobility in the title focus on at least one of these modes, including shared schemes. Although most papers consider more than one mode, the majority do not consider a wide range of modes. Shared forms of mobility have received more attention than privately owned transport modes. Interestingly, the growing literature on cargo-bikes does not appear under the label micromobility.

Most papers are empirical, but there are also seven reviews. The topics researched vary widely, ranging from traffic flows, distribution of stations or fleet, parking, safety, and equity, to travel behaviour (see Table 1 and Table 2).

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[2] We used the following search string:
TITLE (micromobility) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar"))

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Table 1. Definitions of micromobility in the scientific literature.

Reference	Country studied	Definition of micromobility provided	Detail of Definition[3]	Reference to main external definitions
Lazarus et al. (2020)	USA	Not really	'By enabling users to access a fleet of publicly available shared personal transportation devices on an as-needed basis, shared micromobility offers on-demand, low-emission public transportation options that can help to reduce congestion and emissions, as well as improve public health within urban areas'	
Moran et al. (2020)	Austria	No		
Lo et al. (2020)	New Zealand	No		
O'hern & Estgfaeller (2020)		Yes	"Microvehicles encompass both traditional and emerging vehicle types, from conventional bicycles and powered-two wheelers, through to power-assisted e-bikes, e-scooters and new vehicles such as electric skateboards and "hoverboards"". The paper also discusses the ITF and SAE definitions.	ITF, SAE
Sokołowski (2020)	EU-27 and UK	No		
Fitt & Curl (2020)	New Zealand	No		
Oeschger et al. (2020)		Yes	The paper discusses the ITF definition at length.	ITF
Esztergár-Kiss & Lizarraga (2021)	Spain, Germany, Denmark, Israel, Sweden	Yes	'Micromobility can be defined as the usage of bicycles, scooters, or small vehicles for typically short urban trips. It can be electric or traditional, and it can be privately owned or shared'	
Fonseca-Cabrera et al. (2021)	Spain	Yes	'It includes all transportation modes that allow their users to make a hybrid usage and behave either as a pedestrian or as a vehicle at their convenience or when necessary. Defined as such, micro vehicles include all easy-to-carry or easy-to-push vehicles allowing for the augmentation of the pedestrian. They can range from lightest rollers and skis to the heaviest two-wheeled, self-balancing personal transporters. They can be motorized or non-motorized, shared or privately owned.'	
Meng & Brown (2021)	USA	Not really		
Zakhem & Smith-Colin (2021)	USA	No		
Noland (2021)	USA	No		

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[3] References have been removed from quotes for ease of reading.

Pande & Taeihagh (2021)	Singapore	Yes	"Theoretically, micromobility constitutes all passenger trips of less than 8 km (5 miles), which account for as much as 50 to 60 percent of today's total passenger miles travelled in China, European Union, and the United States. Micromobility devices can be both human-powered or assisted by electricity. The powered micromobility devices comprising electric scooters or e-scooters, e-bikes, hoverboards, electric unicycles, and e-skateboards have recently become popular." This is followed by a discussion of the ITF and SAE definitions.	ITF, SAE
Balacco et al. (2021)	Italy	No		
Bai & Jiao (2021)	USA	No		
Hosseinzadeh et al. (2021	USA	No		
Hilgert et al. (2021)		No		
Sengül and Mostofi (2021)	n/a	Yes	"Micromobility is defined as small and lightweight (less than 500 kg) modes of transport with speeds less than 25 km/h, most of which are used individually, such as the use of bicycles, and with the standing position, such as the use of scooters. E-micromobility vehicles are different from micromobility vehicles due to their motorized powertrains, which are electric, as in e-bikes, e-scooters, and e-skateboards."	Wikipedia; Deloitte: (https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/micro-mobility-is-the-future-of-urban-transportation.html)
McQueen et al. (2021)	n/a	Yes	"We define micromobility modes as small, lightweight human-powered or electric vehicles operated at low speeds, including docked and dockless e-scooters and bike share systems."	SAE, Didiu (https://micromobility.io/blog/2019/2/23/the-micromobility-definition)
Amoako et al. (2021)	Ghana	Yes	"Defined as transport modes whose speeds do not exceed 45 km/h, micromobility products such as scooters, bicycles, hover-boards, and skateboards not only appeal to the young but also offer cheaper, cleaner, healthier, and quieter transport options"	Dediu

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de Bortoli (2021)	France	No		
Brown (2021)	USA	No		
Fazio et al. (2021)	Italy	Yes	“Micromobility is a widely used term for low-speed modes of transport based on the use of electric-powered personal micro vehicles, such as e-scooters. E-bikes can be included in this definition as they have been in the USA, even if in some countries, such as Italy, micromobility usually refers to small electric devices, thus excluding e-bikes.” The paper also mentions that micromobility “is used to indicate new types of transport modes that mainly use electric-powered personal mobility vehicles, such as hoverboards, segways, e-scooters, monowheels and e-bikes. They can be rented or shared vehicles or privately owned.“	
Sandoval et al. (2021)	USA	No		
Reck et al. (2021)	Switzerland	No		
Serra et al. (2021)	Portugal	Yes	“The category of micro-vehicles is quite broad, ranging from human-propelled vehicles to electric and internal-combustion ones, with speeds typically reaching up to 45 km/h.” Followed by a discussion of the ITF and SAE definitions.	ITF, SAE
Askarzadeh & Bridgelall (2021)	USA	Not really	“Micromobility is an evolving form of transportation modality that uses small human- or electric-powered vehicles to move people short distance”	
Luo et al. (2021)	USA	No		
Sun et al. (2021)	USA	Not really	“These small, lightweight mobility options (commonly referred to as micromobility) build on a foundation of shared station-based manual bicycle systems, and have been extended in the past few years to include additional vehicles such as dockless bikes, and electric bikes, and electric scooters.”	
Aman et al. (2021)	USA	Not really	“Micromobility solutions include small-scale vehicles, such as bicycles, scooters, skateboards, segways, and hover-boards, can be human-powered or electric, and often cover short-distance trips. Shared micromobility programs, such as docked and dockless bikes and, recently, dockless electric scooters (i.e., e-scooters), have become increasingly ubiquitous in cities worldwide.”	
Freire de Almeida et al. (2021)	Portugal	No		
Feng et al. (2022)	USA	No		
Bretones & Marquet (2022)		Yes	“The term e-micromobility is a broad concept that has drawn multiple definitions. Consensus definitions seem to gather smaller-scale, lightweight vehicles, electrically powered, operating at speeds up to 25 km/h, that are mainly used for trips up to 10 km (Milakis et al., 2020; Institute for Transportation and Development, 2021). E-MM vehicles can be privately-owned or used through a shared service. (...) In this line, the definition provided by the International Transport Forum (ITF) is more inclusive and defines e-micromobility as: “vehicles with a mass of no more than 350 kg (771 lb) and a design speed no higher than 45 km/h” (International Transport Forum, 2020).	ITF

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			For this literature review, we define e-MM as lightweight vehicles (weighting less than 35 kg), which are electrically powered and with a maximum speed of 25 km/h, including then e-bikes and e-scooters. We are therefore excluding larger and more powerful vehicles, such as e-speed bikes, e-mopeds, and e-motorcycles. Also, this selected definition let us include other modes such as segways and hoverboards.”	
Zhao et al. (2022)	China, India, Japan and USA	Yes	“micromobility devices include motor scooters, powered two-wheelers, motorcycles, mopeds, bicycles, e-bikes, pedal-assisted bicycles, speed-pedelecs, mobility scooters, standing scooters, and e-scooters.”	
Asensio et al. (2022)	USA	No		
Sun & Ertz (2022)		Yes	“Micromobility refers squarely to vehicles that are smaller than cars, such as bicycles or scooters”	
Hamerska et al. (2022a)		No		
Pazzini et al. (2022)	Norway	Yes	“In the report written by the International Transport Forum (ITF), micromobility is defined as: “[…] the use of micro-vehicles: vehicles with a mass of no more than 350 kg (771 lb) and a design speed no higher than 45 km/h”. This definition includes both human-powered and electrically assisted vehicles such as bicycles, e-bikes, kick scooters, and e-scooters but also skateboards, one-wheeled balancing boards, and four-wheeled electric micro-vehicles”	ITF
Sanders & Karpinski (2022)		Yes	“Micromobility refers to “a category of modes of transportation that includes very light, low-occupancy vehicles such as electric scooters (e-scooters), electric skateboards, shared bicycles, and electric pedal assisted bicycles (e-bikes)” [1]. In the past, many devices, including Segways, golf carts, and electric wheelchairs have been considered micromobility devices, but a new taxonomy from SAE International classifying powered micromobility devices includes only vehicles weighing less than 500 lb and having a top speed of 30 mph, which excludes the aforementioned devices”	SAE
Hamerska et al. (2022b)	Poland	Yes	“H. Dediu (2019) characterizes micromobility as a system of individual urban transportation utilizing primarily means of transportation powered by electricity, weighing no more than 500 kg (Bruce, 2018; Dediu, 2019). Micromobility is a concept, which assumes use of small, lightweight, zero-emission Personal Mobility Devices (PMD) that enable covering of short distances in transportation solutions, most frequently in the initial or the final stretch of the planned travel”	Dediu
Lanza et al. (2022)	USA	No		
Fan & Harper (2022)	USA	Yes	“Micromobility (defined as docked or dockless shared bikes, e-bikes, scooters, e-scooters, skateboards, etc.)”	
López-Dóriga et al. (2022)	Spain	No		
Xu et al. (2022)	USA	No		
Elmashhara et al. (2022)		No		

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Fang (2022)	USA	Yes	“The Society of Automotive Engineers (SAE) defines micromobility vehicles as “primarily designed for human transport,” for use on paved facilities, no greater than 500 lb in curb weight, and have a top speed of no greater than 30 miles per hour (SAE, 2019). While the SAE taxonomy is limited to fully or partially-powered devices, human-powered devices can provide similar mobility. This paper discusses injuries related to the use of eight devices: bicycles, motorized bicycles, kick scooters, motorized scooters, skateboards, motorized skateboards, hoverboards, and devices presumed to be Segways.”	SAE
Folco et al. (2022)	Italy	No		
Pérez-Zuriaga et al. (2022)		No		
Arias-Molinares et al. (2022)	Spain	No		
Schwinger et al. (2022)	Germany	Not really	“bike-, scooter-, and ride-sharing have become available to complement the available transportation modes. These novel modes, often summarized as micromobility, have in common that they are most often accessed with the traveler’s smartphone and offer personalized and flexible mobility services.”	
Psarrou Kalakoni et al. (2022)	France	Yes	“The term “micromobility” is used widely to describe modes of individual transportation that are characterized by limited use of space and relatively low mass. However, apart from the vehicle characteristics, a rather mobility-oriented definition of the term includes all transportation modes that allow their users to make a hybrid usage and behave either as a pedestrian or a vehicle at their convenience (e.g. to cross a road or board on a bus) when necessary (Christoforou et al., 2021). These can include a wide range of vehicles, from bicycles and electric scooters to segways, kick-scooters, single-wheel boards, and other. They can be either motorized or non-motorized modes, shared or privately owned.”	
Felipe-Falgas et al. (2022)	Spain	Yes	“Micromobility, consisting of private or shared lightweight vehicles, which operate at low speeds and are used for short trips [Roig-Costa, et al., 2021], includes vehicles such as e-bicycles, e-scooters, and e-mopeds. Many authors have theorized that micromobility characteristics, including its flexibility, sustainability, and affordability make them ideal for substituting more private vehicles that contribute to pollution (Bduljabbar et al., 2021).”	
Medina-Molina et al. (2022)	Spain, Portugal, Italy, France, Germany, Turkey and the United Kingdom	Yes		

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Castiglione et al. (2022)	Italy	No		
Nigro et al. (2022)	Italy	Yes	“In this paper, micromobility, although not yet universally defined (Eccarius and Lu, 2020), refers to a range of small, lightweight vehicles typically operating at low speeds (comparable to a bicycle) and personally driven by users. Thus, micromobility devices can include both powered (Sandt, 2019) and unpowered ones, such as bicycles, electric scooters, electric skateboards, shared bicycles, and electric pedal assisted bicycles.”	
Štefancová et al. (2022)	Slovakia	No		
Romm et al. (2022)	USA	No		
Bylieva et al. (2022)	Russia	No		
Peng et al. (2022)	USA	No		
Liao & Correia (2022)	n/a	Yes	“The term micromobility first appeared in 2017 and denotes those vehicles which are light (less than 500 kg) and designed for short distances (less than 15 km). It mainly consists of (conventional and electric) bikes and scooters, while it also includes other less common modes such as skateboard, gyroboard, hoverboard, and unicycle”	Wikipedia

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Table 2. Focus of papers in micromobility in the scientific literature.

Reference	Focus of paper												Type of (element of) paper						Topic
	Micromobility	E-scooter	Shared e-scooter	E-bike	Shared e-bike	Shared bikes	E-moped	Shared e-moped	Bicycle	Regular kick scooter	motorcycle	Motorized skateboards, hoverboards, segways	Empirical	Review	Conceptual	Editorial	Desk review laws	Case study	
Lazarus et al. (2020)					x								x						Impact shared e-bike on shared bike
Moran et al. (2020)			x										x						Spatial coverage and regulations
Lo et al. (2020)			x										x						Perception of regulations
O'hern & Estgfaeller (2020)	x													x					Publication analysis
Sokołowski (2020)		x															x		Law and regulations
Fitt & Curl (2020)			x																Social practice
Oeschger et al. (2020)	x													x					Integration with public transport
Esztergár-Kiss & Lizarraga (2021)	x												x						Travel behavior
Fonseca-Cabrera et al. (2021)		x											x						Travel behavior and safety
Meng & Brown (2021)			x		x								x						Geographical inequalities
Zakhem & Smith-Colin (2021)		x											x						Parking and road use
Noland (2021)			x		x	x							x						Weather
Pande & Taeihagh (2021)		x																x	Governance
Balacco et al. (2021)		x	x	x	x								x						E-charging stiations
Bai & Jiao (2021)			x										x						Equity
Hosseinzadeh et al. (2021			x			x							x						Weather
Hilgert et al. (2021)			x			x							x						Data and forensic analysis
McQueen et al. (2021)	x														x				GHG, equity, sustainability
Amoako et al. (2021)									x				x						Acceptability and micromobility
Şengül & Mostofi (2021)		x	x	x										x					Review impacts
de Bortoli (2021)		x	x			x		x					x						LCA shared/private

Brown (2021)			x										x			Parking policy
Fazio et al. (2021)		x	x										x			Network and route planning
Sandoval et al. (2021)			x										x			Parking
Reck et al. (2021)			x		x	x							x			Mode choice
Serra et al. (2021)		x												x		Safety
Askarzadeh & Bridgelall (2021)						x							x			Bike sharing stations
Luo et al. (2021)						x							x			Network design
Sun et al. (2021)			x		x								x		x	Energy
Aman et al. (2021)			x		x	x							x			Equity
Freire de Almeida et al. (2021)		x											x			Network
Feng et al. (2022)			x										x			Traffic flow
Bretones & Marquet (2022)	x													x		Sociopsychological factors of adoption
Zhao et al. (2022)	x												x			Injuries
Asensio et al. (2022)		x	x										x			Car substitution
Sun & Ertz (2022)					x	x							x			GHG and shared micromobility
Hamerska et al. (2022a)	x	x											x			Quality of shared services
Pazzini et al. (2022)		x	x										x			Travel behavior
Sanders & Karpinski (2022)	x														x	Micromobility & autonomous vehicles
Hamerska et al. (2022b)			x										x			Quality of shared services
Lanza et al. (2022)	x	x							x				x			Travel behavior and infrastructure
Fan & Harper (2022)	x												x			Car substitution
López-Dóriga et al. (2022)	x												x			Health impacts
Xu et al. (2022)	x												x			Air quality
Elmashhara et al. (2022)	x													x		User behavior and shared micromobility
Fang (2022)	x	x		x						x		x	x			Injuries
Folco et al. (2022)	x												x			Network planning
Pérez-Zuriaga et al. (2022)		x											x			User behavior and safety
Arias-Molinares et al. (2022)	x												x			Travel patterns and micromobility
Schwinger et al. (2022)	x		x		x								x			Public transport and micromobility
Psarrou Kalakoni et al. (2022)	x												x			Neighborhood suitability for micromobility
Felipe-Falgas et al. (2022)			x		x			x					x			LCA of shared micromobility

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Medina-Molina et al. (2022)	x						x		Sociotechnical transitions
Castiglione et al. (2022)		x	x	x	x		x		City logistics
Nigro et al. (2022)	x						x		Car substitution
Štefancová et al. (2022)			x			x	x		Impact of COVID-19 on micromobility
Romm et al. (2022)						x	x		Multimodality
Bylieva et al. (2022)	x						x		Digital and physical aspects of shared micromobility
Peng et al. (2022)			x			x	x		GHG and shared micromobility
Liao & Correia (2022)	x							x	E-carsharing and micromobility

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3.3. Frequently referenced micromobility definitions by international societies and organizations

The definitions that the academic papers discussed above mostly draw on are from two institutions, the International Transport Forum (ITF) – 6 papers, and the Society of Automotive Engineers (SAE) – 6 papers. In the definition of the intergovernmental ITF, which is closely linked to the OECD, speed and weight are two key characteristics of micromobility. According to its 'Safe Micromobility' report, micromobility refers to "the use of vehicles with a mass of less than 350 kilogram (kg) and a design speed of 45 kilometers per hour (km/h) or less" that may be either "human-powered" or "electrically-assisted" – although the report later states that fuel tanks are an option too (ITF, 2020, p. 14). The ITF notes that micromobility modes vary considerably in terms of design, stating that these vehicles are "polymorphic'' and "cannot be defined by the number of wheels, nor by the riding position, which can be seated or standing'' (ITF, 2020, p. 14-15). It distinguishes four types of micromobility vehicles, based on the two key defining characteristics, i.e. speed ("unpowered or powered up to 25 km/h (16 mph)" and "powered with a top speed between 25-45 km/h (16-28 mph)") and mass (below "35 kg (77 lb)" and "35 – 350 kg (77 – 770 lb)") (ITF, 2020, p. 16).

According to the Society of Automotive Engineers (2019)'s defining aspects are power type, weight, speed, and purpose. The "wheeled vehicles" should be under 227 kilograms (500lb) and have a speed below 48km/h (30mp/h). It is important to note that the SAE's definition focuses solely on "powered micromobility", either partially or fully powered, thus excluding exclusively human-powered vehicles. Moreover, its definition states that it is for "vehicles that are primarily designed for human transport and to be used on paved roadways and paths". The SAE also has a classification system for describing vehicle types. Key characteristics include curb weight, vehicle width, maximum speed and power source, each with 2-4 options. Furthermore, the types of micromobility are distinguished according to centre column, seat, operable pedals, floorboard/foot pegs, and self-balancing (Society of Automotive Engineers, 2019).

The differences between the ITF and SAE definitions may appear small (see Table 3, section A). Still, they impact which modes are considered micromobility (see Table 3, Section B). This may in part explain the variety of definitions and inclusions of modes in the scientific literature. For example, many human-powered vehicles – including bicycles – would be included in micromobility according to ITF's but not SAE's definition. Excluding of human-powered vehicles has associated public health implications and is also Western-centric. SAE's definition focuses solely on personal transport and excludes freight, while the ITF's definition covers both. The ITF definition makes no explicit reference to wheelchairs but includes a mobility scooter in the visual. The SAE definition does not refer to mobility options used by those with mobility problems.

Table 3. Comparing the micromobility definitions, modes, and purposes in the ITF and the SAE (key differences in italics).

Section A: Comparing the micromobility definitions		
	ITF	**SAE**
How powered?		
Human	*Yes*	*No*
Assisted	Yes	Yes
Fully	No	Yes
Electric motors	Yes	Yes
Combustion Engines	Yes?	Yes
Others		
Top weight	*350kg*	*227 kg*
Top speed	45 km/h	48 km/h
Purpose	*All mobility*	*Only personal transport*
Number of wheels	No	No

Has sub-categories?	Yes, 4	Yes, many
Section B: Modes and purposes considered as micromobility		
Modes and Purpose	**ITF**	**SAE**
Bicycle	yes	
E-bike	yes	yes
E-scooter (standing)	yes	yes
E-scooter (sitting)	yes	yes
Cargo-bicycle	yes	no
e-cargo-bicycle	yes	if for transporting people: yes; for freight: no
Skateboard	yes	no
Hoverboard	yes	yes
All-terrain vehicle	yes (depending on weight)	yes (depending on weight)
Human Transport	yes	yes
Freight Transport	yes	yes

4. Dimensions and characteristics of micromobility

The analysis in section 3 has shown how the academic literature primarily uses vehicle examples and technical characteristics to define micromobility. Vehicle weight, range, speed and primary usage are deemed key. Yet, these features capture only part of what micromobility is. We argue for a socio-technical perspective (Geels, 2005) where vehicle technology is only one of several dimensions that should be considered, also driven by our mobilities approach (Sheller 2018).

This socio-technical mobilities perspective shaped the identification of the seven dimensions presented in this section. These are also derived from the analysis of micromobility related concepts (section 2) and from the use and definitions of the term (section 3). They are further informed by the authors' expertise in the broader mobility and transport fields, including current micromobility scholarship.

Figure 2 gives an overview of the seven dimensions that we consider important for a socio-technical conceptualisation of micromobility – namely factors relating to the environment; human, social and cultural considerations; vehicle technology; infrastructure; economic; public health; and regulations and policy. These dimensions are discussed further below, building up the paper's new definition of micromobility in section 5.

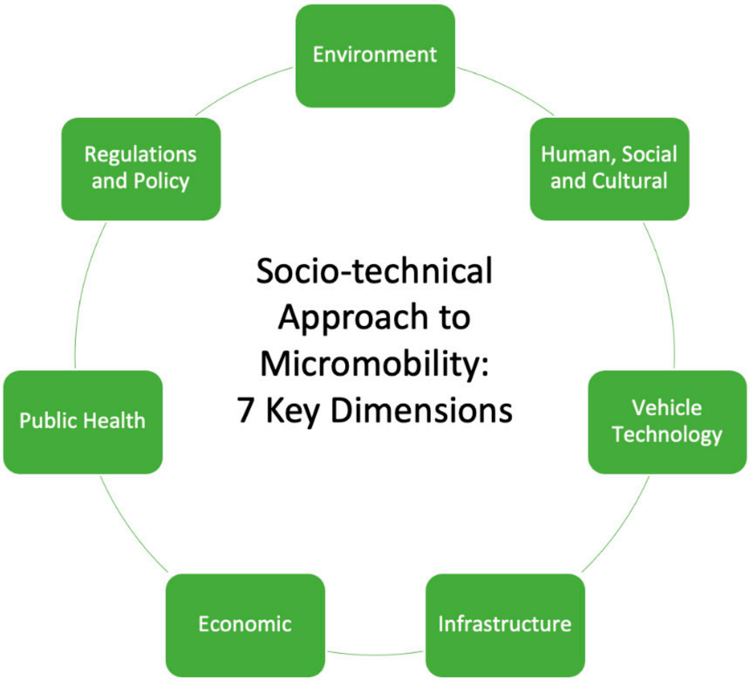

Figure 2. The Socio-technical Approach to Micromobility: 7 Key Dimensions.

4.1. Environmental dimension

As transport emissions are rising globally and urgent calls are issued for their reduction (IPCC, 2022), being 'micro' in terms of energy use is key to micromobility's significance. The environmental dimension underlines how micromobility offers a form of travel with the potential to decarbonize personal and freight transport. Most micromobility vehicles have relatively low energy requirements because they are small and light enough to be manoeuvred by one person, as discussed later, we consider this to be a key part of the definition. Walking is logically, therfore, also a form of micromobility, given that it has the lowest energy requirements of any form of transport. Recent studies estimate that large-scale take-up of LEVs (many of which are considered micromobilities) could lower personal transport-related CO2 emissions by 44% in Germany (Brost et al., 2022), while several studies assess the potential CO2 savings of shifting from car to e-bike at 12-50% (Cairns et al., 2017; McQueen et al., 2020; Philips et al., 2020). Partially or fully electrically and human-powered micromobility vehicles have zero greenhouse gas (GHG) emissions at the point of use. However, all-electric vehicles will incur upstream emissions from electricity generation – depending on how the electricity is generated, stored and delivered. There are also non-tailpipe emissions of toxic particulates from brake and tyre wear – but these are very small compared to those from car use.

GHG (expressed in carbon dioxide equivalent, CO2-eq) from vehicle manufacture, use and recycling and disposal also factor into the environmental impact metric and are generally lower for micromobility options than for cars (de Bortoli, 2021): Owning and using lighter, less material-intensive and much more energy efficient vehicles is less carbon intensive. Table 4 shows comparable figures for a range of vehicles, taken from a single source (Cazzola & Crist, 2020). Specifically, this table provides three key measures of the emissions:

- Per vehicle emissions generated by vehicle and battery manufacture, assembly, delivery to point of purchase, and disposal.
- Per vehicle emissions generated by the operational services involved in shared schemes
- Emissions per passenger km directly generated by vehicle use.

Component figures from the source are given, rather than traditional lifecycle figures (for 'all emissions' per km or per passenger km travelled), since lifecycle calculations are strongly influenced by lifetime mileages. Since a paradigm shift to micromobility vehicles would arguably involve a shift to more localised living and working patterns, and/or combined use with public transport for longer journeys, to understand the scope for emission savings, it is therefore more meaningful to consider emissions separately in terms of 'fixed' emissions (from vehicle creation and disposal) and emissions that result from (different types of) use. Lifecycle figures suggest, for example, that using an ICE car compared to an e-bike would result in emissions that are only 6x greater[4].

However, according to the data given in Table 4, the 'fixed' emissions associated with manufacturing, assembling, delivering, and disposing a private ICE car are 39 times greater than the same emissions associated with a private e-bike, and the per passenger.km emissions from use are 11 times greater[5]. Other researchers suggest differences may be even more substantial. Consequently, a shift to micromobility has the scope to deliver considerably greater emissions savings than a consideration that lifecycle considerations might imply. Put another way, suppose someone only travels 2,000 km per year and plans to keep whatever vehicle they buy for 10 years: according to the Table 4 figures, for that type of travel, buying and using an e-bike would generate 0.4 tonnes of CO2-eq, whilst buying and using an e-car would generate 12.8 tonnes of CO2-eq. A key variable in these calculations is the expected lifetime of each micromobility vehicle, which– as discussed in the economic dimension below – varies across modes.

Micromobility also has implications for local air quality and noise levels. Human-powered and electric vehicles have substantial benefits in terms of local air quality, compared to conventional combustion vehicles. Often overlooked or framed as a safety hazard to pedestrians, micromobilities' much lower noise pollution levels are also potentially a key benefit (Bakker, 2018). Electric bikes and e-scooters are generally not much louder than their acoustic versions. By contrast, electric cars are often not quieter than ICEs at higher speeds. The environmental dimension of our socio-technical understanding of micromobility is closely linked to the human, social and cultural elements of micromobility that are explored in the following sub-section.

Table 4. Comparing average GHG emissions based on (Cazzola & Crist, 2020).

	Average GHG emissions (in gCO_2-eq) for		
Transport mode and operation	(a) Vehicle and battery manufacture, assembly and disposal (including fluids), plus delivery to point of purchase	(b) Operational services (per vehicle)	(c) Energy use, whilst in use, per passenger km (including emissions from fuel production)
Bike	100,398	0	0
Shared bike	128,454	136,111	0
Private e-bike	168,510	0	11.8
Shared e-bike	204,595	136,111	11.8
Private electric step scooter	172,685	0	6.2
Shared electric step scooter (new generation)	374,001	140,886	6.7
Private moped (ICE)	391,272	0	54
Private moped (BEV)	480,145	0	20

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[4] Cazzola and Crist (2020) suggest lifecycle figures of 24gCO2-eq per pkm for a private e-bike and 150gCO2-eq per pkm for an ICE private car.

[5] Other papers suggest even lower figures for the use of micromobility modes. Specifically, Cazzola and Crist (2020) assume energy use of 21Wh/km for e-bikes. However, for example, Weiss, Cloos and Helmers (2020) suggest a mean value of 7Wh/km for e-bikes (see their Table 1), which is more in line with advertised battery ranges.

Private car (ICE)	6,496,825	0	125.6
Private e-car (BEV)	11,339,015	0	71.5

Data taken from (Cazzola & Crist, 2020), and associated online spreadsheet of calculations: life-cycle-assessment-calculations-2020.xlsx (live.com) Specifically, data are taken from the 'Total' worksheet, as follows: (a)= rows 113 and 114; (b) = row 116; (c) = row 101. Infrastructure emission figures are not included given the greater uncertainty associated with calculations, but those given are lower for micromobility vehicles than for cars. ICE = internal combustion engine (i.e. conventional fossil-fuelled vehicle) BEV = Battery electric vehicle (i.e. fully electric vehicle)The full range of assumptions used to generate the figures is given in the source report.

4.2. Human, social and cultural dimension

People travel and move goods to meet their mobility needs, wants and musts. Micromobilities are one way to fulfil these needs. Examining the social dimension reveals who does or does not use micromobility, why, for what purpose, and how social and cultural contexts matter. It also includes geographical considerations: cities, regions and countries cultivate different cultures and combinations of micromobility modes, such as the Dutch high cycling share but no use of e-scooters, or the American low cycling share but strong e-scooter usage in large cities.

To date, certain micromobility modes have appealed more to some user groups or social groups than others (Melia & Bartle, 2021; Mitra & Hess, 2021). Age, gender and, socio-economic status all play a role (6-t for Voi, 2021). E-scooters have been popular with the younger generation, for example, while e-bikes (initially) attract older generations and the physically less able (Spencer et al., 2019). Age can be a criterion for access. For example, in the UK only those over 18 are allowed to use shared e-scooters, whilst e-bike use is limited to 14+. Such age restrictions should be up for debate particularly if the goal is to foster less car-dependent travel patterns from a young age. Shared micromobility services rely on a limited user base, and in places like Zurich, for instance, this base is comprised mainly of young, well-educated, affluent men (Reck & Axhausen, 2021). While there is a significant white/male/middle-class bias in the West, class biases also play a part in other countries and cultures (6-t for Voi, 2021; Hasan et al., 2019).

Households who do not own cars and individuals without access to a car because of their age or income, often have limited access to a full range of services and facilities. Micromobility arguably has the potential to reduce social exclusion (Tyler & Lucas, 2004), since access costs are typically lower, and vehicles are usable by a wider range of people. Though cheaper by comparison, access costs of micromobility still may be substantial, while shared services may often be in places where operators can maximise revenue rather than serving those where need is the greatest. This means that it is important to identify opportunities for promoting micromobility in areas that are vulnerable to car-related economic stress and that also have a high capability of replacing car km with micromobility. If supported appropriately, encouraging micromobility in such locations could contribute to relatively equitable carbon reduction (Philips et al., 2022).

The potential for micromobility is particularly high for the short and medium trips that people use most often like commuting, shopping, bringing children to school, and visiting friends or family (Abduljabbar et al., 2021). However, some types are more suitable for particular trips: e-cargo bikes and trikes are convenient for transporting cargo (shopping, children); e-scooters for shorter trips in towns and cities, and e-bikes for intra-urban and rural journeys (Philips et al., 2022) and for access to public transport (Azimi et al., 2021).

Most micromobility types do not require extensive skills, but many do require some basic skills (e.g. cycling) are required, and for safely riding an e-scooter, there are skills to be learnt and acquired (Department for Transport, 2022). All micromobility options could or should benefit from some form of training. Skills are often provided via informal settings such as in the family. Formal schemes (e.g. cycle or scooting training in schools) also exist – most often geared towards children but exclude adults or those not benefitting from a micromobility-supportive context (e.g. migrants). More training is needed for heavier e-cargo bikes, high speed e-scooters and e-bikes. Knowledge of traffic regulations is essential but not currently legally regulated in most cases. At the same time, training

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for motorists also needs to centrally include micromobility awareness and regulations, for example as part of licence exams.

This leads to the key issue of perceived safety and crash risks for micromobility. The current debate over-simplifies safety issues, casting some modes as safe and other as unsafe, and underplaying the role of automobility. In practice, it is not the rider but mostly the mode's features (speed, safety features), the infrastructure, the traffic policy, and societal and cultural contexts that determine safety (Branion-Calles et al., 2019; Sanders et al., 2020). Micromobility's actual - and perceived - safety varies widely between countries and cities but can often be a key barrier to uptake (ITF, 2020; Sanders et al., 2020; Sulikova & Brand, 2021).

4.3. Vehicle technological dimension

A vehicle, broadly defined as a machine that transports people or cargo (Halsey, 1979), often forms a key dimension of how micromobility is defined, including vehicle shape, number of wheels, size of wheels, number of seats, and centre of gravity. This is problematic. We argue that the use of a vehicle is not essential: walking is an important part of our understanding of micromobility. Walking may or may not include the pushing or pulling of a vehicle, such as a pushchair, a shopping trolley or a cart.

We therefore propose to include fully and partially powered as well as non-powered 'micro' vehicles that allow for a sit-down, recumbent and stand-up positions, with any number of wheels. Some vehicles can be used for carrying (cargo or people) loads or with physical impairment, often with 3- or 4-wheel design and lower, easy access (Cazzola & Crist, 2020). A maximum vehicle weight of 350kg, as per the ITF definition, makes sense in terms of 'micro' energy use and safety. In contrast, a car will usually weigh over 1000kg or more. In terms of vehicle speed, two characteristics are important: design speed (i.e. vehicle's designed maximum speed) and, for electric vehicles, the max. assistance speed (i.e. the speed at which a motor ceases to assist or accelerate). Both can vary, depending on the vehicle type. Beyond the ITF and SAE definitions (see 3.3), speed restrictions also vary by country, particularly for e-bikes. According to UK, EU and Australian laws, e-bike assistance from the motor must cut out at 25km/h (15.5mph), whilst in the US it is 20mph (32km/h). It may be practical to consider 32 km/h the common threshold for many forms of partially- or fully powered micromobility, though with a sub-category that can achieve speeds of up to 45km/h (Cazzola & Crist, 2020). Human-powered micromobility can exceed these speeds (e.g. race cycling).

Another element is payload capacity. It refers to the amount of cargo and/or the number of passengers that a vehicle can carry in addition to the driver. For micro scooters, the extra payload is very limited. In contrast, e-cargo cycles are capable to transport 50-250 kg of cargo, and some even up to 500 kg) (Narayanan & Antoniou, 2021). Some types may add trailers to increase payload capacity.

Vehicle power, range and specific energy consumption are yet another criterion. 'Motorisation' may be specified on a continuum – ranging from non-motorized, to motor assistance, to fully motorised. Options include combustion engines and electric powertrains, even though vehicle development and deployment worldwide has recently focussed on fully electric propulsion (Cazzola & Crist, 2020).

Battery capacity (a measure of the available power, in watt-hours, Wh) is a key characteristic here, with associated costs and performance largely determining the vehicle's price and suitability. The capacity of typical e-bike batteries range from 250 Wh (providing between 25 and 50 km in range) to 1,000 Wh, weighting 1.5-5 kg. E-scooter batteries have a capacity of about 500 Wh and weigh 4-5 kg (Kazmaier et al., 2020). Average e-cargo bikes have a battery capacity of around 400-500Wh, providing a range of up to 80 km (Narayanan & Antoniou, 2021), and their batteries are slightly heavier that e-bikes' batteries. A typical e-bike charger would have a 5-amp (A) rating, charging a (small) battery to full capacity in an hour.

Regarding the motor, there are two systems of motor, namely hub-drive and mid-drive (Narayanan & Antoniou, 2021). While the former is meant for frequent riding on even roads with an occasional inclination, the latter is meant for frequent riding on hilly roads with an inclination of

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more than 3%. E-bikes and e-cargo bikes have an electric motor with around. 250 watts in much of Europe (Switzerland: max. 500 watts), with an average weight of 3-4 kg (Bosch, 2022b, 2022a). Average e-scooters feature motor power ranging between 200-500 watts, and higher-performance e-scooters offer a motor power of around 1200 watts (Aguila J, 2022).

As speed e-bikes (sometimes called speed-pedelecs) are more powerful and faster versions of standard e-bikes, the maximum motor output is about 4,000 watts (i.e. 16 times higher than e-bikes), giving assistance to pedalling up to the cut-ff speed of 45 kph. In the EU, speed e-bikes are classified as mopeds in the (cat. L1e-B) that require insurance and license plates. E-mopeds – sit-down scooters – typically have a top speed of 45 km/h, an average range of 43 km, and up to 4 kW for the motors (Schelte et al., 2021). In contrast, average e-bikes, e-cargo bikes, and e-scooters have an average speed of around 25km/h, with significantly higher speeds for higher-performance e-scooters.

'Smart' or connected vehicles equipped with either a one- or two-way flow of digital data are becoming more popular and are essential for shared services. Data-driven services include GPS tracking, geo-fencing (where the electric motor cuts out when outside a predefined geographical area), locking, route guidance, ticketing, and energy consumption monitoring. This is a fast-developing area (Behrendt, 2016; Nikolaeva et al., 2019). The detail of this vehicle-technological dimension of micromobility is important, but always needs to be understood as only one element of a socio-technical approach to micromobility.

4.4. Infrastructure

Micromobility requires appropriate infrastructure. Infrastructure should ideally be of high quality and safe for all user types, particularly for children and other vulnerable users. This often means purpose-built infrastructure like segregated lanes, tracks and junction designs. Since the 1920s, road space has been increasingly divided by vehicle types, e.g. cars, bikes, and pedestrians – to make way for automobility. Micromobility options may require rethinking whether this is most appropriate way. The quality of the road surface is of particular importance for small-wheeled vehicles. Reimaging roads' design, speeds, and per-mode space allocation may be required to accommodate for potential larger volumes of micromobility. Geofencing may offer the potential to ensure that micromobility modes are speed limited (in specific areas/at specific times) to ensure compatibility between different travel modes. Low-speed/traffic zones (30 km/h) and play streets (where micromobility has priority and cars have to go at low speeds as 'guests') can reduce speed variability between modes or give priority to micromobility modes, both of which make it safer for people to use the slower modes. Furthermore, encouraging more localised patterns of living both facilitates, and is facilitated by, greater use of micromobility vehicles. Many examples and issues mentioned under the infrastructure dimension are equally about policies and regulations (see 4.7), highlighting the close connection between the dimensions.

As 'micro' suggests, micromobility vehicles typically have a lower spatial footprint than car travel – for both moving and parking. For moving, the ratio is about 1:4 for biking:car, 1:2 for e-cargo bikes:car (Ewert et al., 2020), 1:5.2 for e-scooters:car, and 1:6.5 for pedestrians:cars (ITF, 2021). For storage, the parking space required by one car can fit about 12 bikes, 15 e-scooters or 3 cargo-bikes.

Easy access to secure vehicle parking close to origins and destinations is key. It shapes how people choose their daily mobilities. Users, shared micromobility operators and local authorities fear vandalism and theft (Gössling, 2020). To encourage micromobility use, policy makers, transport operators, businesses and institutions need to make parking secure, easy and free or low cost, both in terms of quality and quantity, and with an eye to the great variety of micromobility modes. This is relevant both for public and private spaces and for shared and privately-owned modes. Providing secure and safe parking for micromobility around key destinations (shopping areas, railway stations, etc.) and at homes is central. It also facilitates multi-modal integration.

Micromobility is increasingly integrated with other forms of mobility, particularly public transport. Key issues are the ease and legality with which micromobility vehicles can be taken on board a train or bus, ease of access to the nearest bus or train station, integration and availability of parking at public transport hubs, and whether shared vehicles are integrated in terms of ticketing and journey routing. Overall, the infrastructure dimension of micromobility is embedded in the mobility systems and the built environment more widely. It is also closely linked to other systems, including energy and ICT.

4.5. Economic dimension

The economic dimension of micromobility has already been hinted in relation to the two main business models: individually owned or shared micromobility. For shared, the two main business models to date have been via docking stations or dockless parking/storage. Most shared systems involve ICT 'enabled' smart connectivity and payment methods. They require vans, trucks or e-cargo bikes to collect, charge, and reallocate e-vehicles, with implications for the carbon footprint (Cazzola & Crist, 2020).

The – private and shared – micromobility sector is rapidly evolving and have seen significant market growth over the last decade, with technologies, regulations, and business models changing quickly and unexpectedly (K. Heineke et al., 2020; ITF, 2021). After significant investment, the market saw several mergers, acquisitions and bankruptcies, also in response to post-Covid conditions and regulatory struggles (K. Heineke et al., 2020; Ratti & Auken, 2019). Still, some forecasts see the market grow from $48.11 billion in 2021 to $300 billion in 2030 (CBInsights, 2021; Edward, 2022; K. Heineke et al., 2020). Access costs to shared schemes vary, but often feature a time and/or distance component, while the costs of providing these schemes include re-location, maintenance and credit card fees (B. K. Heineke et al., 2019).

The technological maturity varies across micromobility options; cycles have been around for centuries so their maturity it is relatively high when compared with recently emerging modes like e-scooter and e-cargo bikes and trikes. The newer micromobility modes that are still evolving will benefit – in terms of cost, performance and sustainability impacts – from further innovation and development in all technical elements.

The cost of manufacturing, purchase – and maintenance – significantly varies according to the type, range and other technical specifications, production volume, location of production and distribution, construction materials, brand, accompanying software, and other factors. In addition to batteries, motors are key components in terms of costs.

'Economic lifetime' is often used in economic analyses of the costs and benefits of vehicles and mobility services. Micromobility features a wide range, from 3 months for some shared e-scooters (Schellong et al., 2019) to eight years for e-bikes (Buchert et al., 2015), and several decades for bicycles, though with figures generally rising over time.

Economic spillovers could include increased spending in local food, retail, entertainment, health, and fitness sectors, though eat-in restaurants might be negatively impacted by micromobility home deliveries (Kim & McCarthy, 2021; Rivlin & McCarthy, 2022). The economic dimension of micromobility is also closely related to public health, as tools such as the WHO's Health Economic Assessment Tool for walking and cycling show.

4.6. Public health dimension

Most micromobility options require some form of physical activity above resting or car driving. This can have significant public health benefits. The level of physical activity needed depends on the vehicle type: walking and cycling are the most active, e-scooters require standing and some pushing off, and electric mopeds are the least active. Micromobility has been shown to improve both physical and mental health (Sanders et al., 2020; Sengül & Mostofi, 2021), even if electrically assisted (Castro et al., 2019). This being said, the main public health risks come from increased mortality/morbidity from crashes and exposure to air and noise pollution – particularly in mixed road traffic (Götschi et al., 2020; Maizlish et al., 2022). Policymakers should consider the large public health-related variation of different micromobility modes. Scholars and policymakers need to consider the synergies between micromobility and active mobility debates, including attention to conflicts and substitution between micromobility modes.

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4.7. Regulations and Policy

The potential of micromobility is also shaped by regulations and policies: the final key dimension discussed in this section. The permitted locations for storage, parking, and use are key characteristics and vary by vehicle type and jurisdiction. For instance, e-bike weight, power, and speed restrictions vary by jurisdiction, typically ranging from 250 to 500 W maximum motor power and 25 to 40 km/h maximum speed with assistance (Bigazzi & Wong, 2020). As mentioned earlier, the UK allows only shared e-scooters to be used on public roads in trial areas, while private e-scooters are illegal on public roads or pavements. Micromobility delivery services – like e-cargo bikes – are often allowed to park in locations forbidden to conventional vans. Still, some private e-cargo bike users do not necessarily have full clarity on when and where they can park and secure their bikes. Parking policies for shared e-scooters have also seen wide variation (Brown, 2021). This policy area is dynamic and subject to change rapidly (both at the national and city level), but is clearly important.

Some micromobility modes are promoted and encouraged vis-a-vis other, less sustainable modes of transport. E-bikes and e-scooters, for instance, are often permitted to be used in clean air zones, city centre pedestrianized zones, and so on. Such policy may help uptake and encourage substitution of other motorized modes (car, bus, taxi/uber, etc.).

In some jurisdictions, riders/users are required to hold a license for public use for some categories of micromobility vehicles. This can be linked to the user's age. Other jurisdictions require riders to carry safety equipment (e.g. helmet, lights) or stipulate third-party insurance as a requirement for use on public roads.

In sum, the seven dimensions of our socio-technical approach to micromobility discussed in this section demonstrated how much we can gain from attending to the practices, policies, cultures, and infrastructures that emerge around the use of these mobility options and shape their uptake. This significantly broadens the prevailing vehicle-focus in micromobility debates and scholarship.

5. New Definition of Micromobility

This section details our proposed new conceptualization of micromobility, drawing on the concepts discussed in section 2, the scholarship analysed in section 3, and the socio-technical dimensions outlined in section 4. For us, micromobility refers to a comprehensive and multi-dimensional concept that encompasses a diverse range of human-powered, partially motor-assisted, and fully powered mobility options primarily designed for short-distance travel.

In our definition, the term "micro" is relative and relates to energy demand, environmental impact, and roadspace utilization, compared to automobility. Micromobility can typically be manoeuvred by one human without motor assistance, at least for short distances. Micromobility includes various modes of transportation, such as walking, cycling, (speed) e-bikes, e-scooters, moped scooters, cargo bikes, rickshaws, wheelchairs, mobility scooters, (e)skateboards, and hoverboards. These modes typically operate at speeds not exceeding 32 km/h (or 45 km/h for faster options) and have a weight (generally significantly) below 350 kg, often offering some (public) health benefits from usage.

Our concept of micromobility extends beyond the physical modes of transportation and encompasses the surrounding ecosystem that enables and supports these mobility options. This includes practices, policies, cultures, and infrastructures that emerge around the use of these mobility options and shape their uptake, including interaction with other systems such as energy and ICT.

The definition emphasizes the movement of both people and cargo, reflecting the diverse purposes these mobility options serve. Micromobility trip lengths are typically less than 15 km with a daily distance travelled of less than 80 km. Figure 3 provides a visual summary of this new conceptualization of micromobility.

This novel definition of micromobility fills the gap in existing vehicle-centric definitions and offers a broader conceptual approach for future transport and mobility studies as well as policy development. A widely accepted and comprehensive definition of micromobility can facilitate the establishment of robust design standards, legislation, evaluation metrics, theorisation and methods, ultimately enhancing our understanding of and attention to this form of mobility.

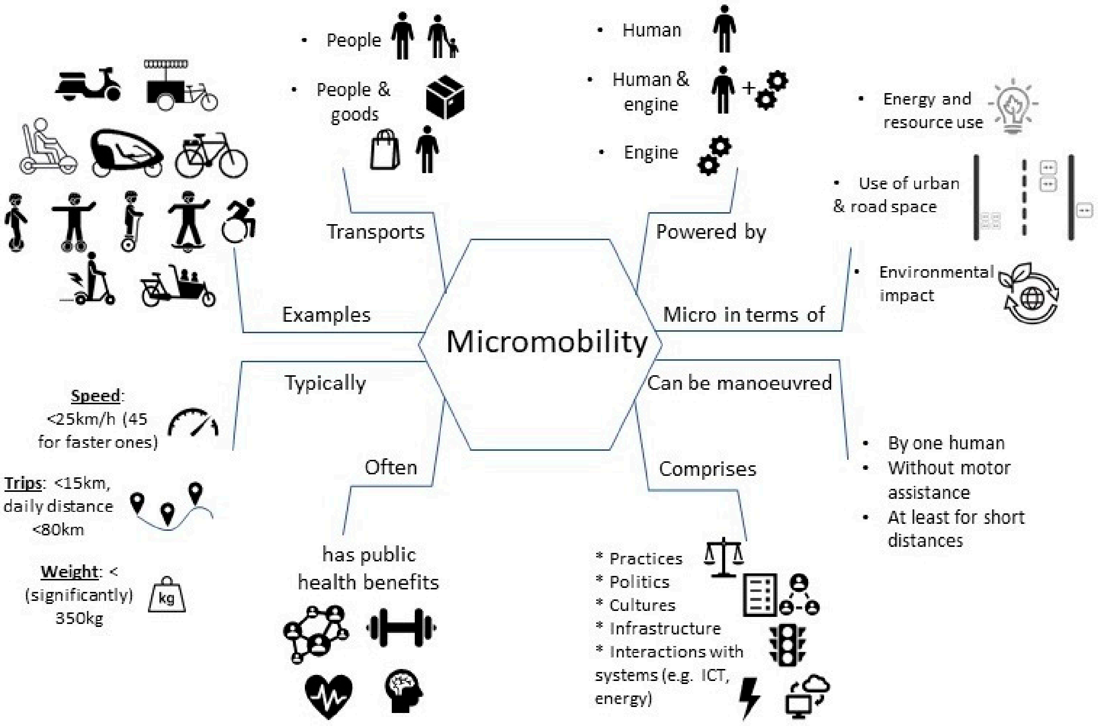

Figure 3. Visualization of our Definition of Micromobility.

6. Conclusion

This paper provides a socio-technical and multi-dimensional conceptualization of micromobility, filling a crucial gap in the existing literature. By considering the broader context and embedding micromobility within related discourses, such as active mobility, non-motorized transport, and light electric vehicles, this study has advanced our understanding of the term and its implications. Unlike previous research that primarily focused on empirical aspects, limited definitions, or the vehicle itself, our approach encompasses wider societal perspectives.

By adopting a multi-dimensional framework, this paper has highlighted the significance of incorporating human, social, and cultural considerations, as well as environmental, economic, public health, as well as regulatory and policy considerations, alongside infrastructure and vehicle technology dimensions. Our definition of micromobility encompasses a wide range of mobility options typically used for shorter trips and manoeuvrable by an individual without motor assistance, at least for short distances. These modes are characterized by their 'micro' attributes, including low energy demand, minimal environmental impact, and efficient use of road space relative to automobile-based transportation. This includes walking. Further elaboration of our definition can be found in section 5 of this paper.

We argue that embracing micromobility-inclusive or micromobility-focused approaches to sustainable mobility transitions presents a credible alternative to the current policy emphasis on electric cars. The latter has proven insufficient in achieving rapid carbon reduction targets (Brand et al., 2020), and lacks the principles of justice and inclusivity (Henderson, 2020) both in the Global North and South.

The potential of micromobility is further amplified when combined with public transport and urban planning. Therefore, future research should closely link micromobility debates with discussions about multi-modal transport (as discussed in section 2), Transit Oriented Development (Jain et al., 2020), Liveable Cities (Nieuwenhuijsen, 2020), and 15-minute cities (Moreno et al., 2021) to leverage and expand upon existing work on cycling and walking.

While this paper has made significant contributions, there are several limitations that offer opportunities for future academic work. These limitations include the lack of detailed historical

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perspectives, a predominantly Western-centric and ableist approach, limited integration of scholarship on walking, and a land-based perspective. Addressing these gaps would enhance the comprehensiveness and inclusivity of research on micromobility.

The socio-technical and multi-dimensional conceptualization of micromobility presented in this paper holds the potential to position micromobility as a central element in transition pathways, aligning with the Sustainable Development Goals (SDGs) (United Nations, 2015), and principles of mobility justice (Sheller, 2018a, 2018b). Moving forward, it is crucial to advocate for a world where micromobility is integral to the financing, strategizing, planning, and implementation of global, national, and local mobility and transport futures. This includes engaging international organizations such as the World Bank, World Health Organization and UN Environment Program, as well as integrating micromobility considerations into countries', regions' and cities' transport and climate change strategies and urban planning.

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