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# Micromobility: Progress, benefits, challenges, policy and regulations, energy sources and storage, and its role in achieving sustainable development goals

A.G. Olabi [a,b,*], Tabbi Wilberforce [b], Khaled Obaideen [a], Enas Taha Sayed [c,d], Nabila Shehata [e], Abdul Hai Alami [a,*], Mohammad Ali Abdelkareem [a,d,*]

[a] Dept. of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates
[b] Mechanical Engineering and Design, Aston University, School of Engineering and Applied Science, Aston Triangle, Birmingham, B4 7ET, UK
[c] Center for Advanced Materials Research, University of Sharjah, PO Box 27272, Sharjah, United Arab Emirates
[d] Faculty of Engineering, Minia University, Elminia, Egypt
[e] Environmental Science and Industrial Development Department, Faculty of Postgraduate Studies for Advanced Sciences, Beni-Suef University, Beni-Suef, Egypt

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ABSTRACT

Micromobility is dominant in urban areas, enhancing the transportation sustainability and assisting in fulfilling the United Nations Sustainable Development Goals (SDGs). This work provides an overall assessment of micromobility: its role under SDGs, policy options, micromobility regulations, emerging technologies, utilisation determinants, energy source, and energy storage. The analysis shows that micromobility could play a major role in achieving the SDGs, specifically SDG 3 (Good Health and Well-being) by lowering toxic gas emissions and reducing projected traffic accidents. Also, the effect on SDG 8 (Decent Work and Economic Growth) by reducing the transportation footprint, on SDG 11 (Sustainable Cities and Communities) by increasing transposition accessibility, reducing traffic congestion and improving the air quality, and equally on SDG 12 (Responsible Consumption and Production) by reducing transportation footprint and increase the sources efficiency. Moreover, micromobility affects SDG 13 (Climate Action) by reducing the greenhouse gases. Furthermore, the analysis shows a clear gap in literature and publications on micromobility, especially in energy management and energy storage area. This review shows that new technology of renewable energy and energy storage could play a significant role in achieving the sustainability of micromobility therefore achieving the SDGs.

## 1. Introduction

The rapid growth in the usage of fossil fuel resulted in massive accumulation of greenhouse gases that resulted in global warming [1,2]. Intensive efforts are being done to control the global warming that resulted in clear climate change and other health issues. In general, there are three different strategies are being used for realizing this target: (1) As a major part of the energy during the operation of conventional processes is lost in form of heat [3,4], therefore, waste heat recovery is considered as an effective method for increasing the efficiency, and thus decreasing the energy consumption [5,6]; (2) the usage of new energy conversion devices that are efficient and has low environmental impacts such as fuel cells [7–9]; and finally (3) developing and usage of renewable energy source that are sustainable and has low or no environmental impacts such as solar thermal [10,11], solar PV [12], wind [13,14], geothermal [15,16], and biomass energies [17–19]. Transportation is one of the main pollution resources as it still depends mainly on the internal combustion engine that produce massive amount of pollutants. Electrification of the transportation sector could significantly reduce the air population. There is a rapid progress in the development of battery electric cars and fuel cells cars that have lower environmental impacts [20–23]. Micromobility is a term that refers to compact, lightweight vehicles with velocities lower than 30 km/h and driven personally by road users (not by another person). Due to the compactness, portability and effectiveness in short-distance urban commutes, they prove better than conventional forms of transportation especially as they are insensitive to traffic jams [24].

Micromobility vehicles are quickly emerging, and the bulk are

* Corresponding authors.
*E-mail address:* mabdulkareem@sharjah.ac.ae (M.A. Abdelkareem).

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provided by micromobility service companies across the world. One business model requires vehicles to be shareable or ones that can be leased (by-the-minute rates) to passengers thus eliminating the need to buy and operate a dedicated conventional car [25]. Cities all over the world are struggling with the detrimental issues pertaining to automobile travel and are working to develop a more efficient urban transit infrastructure. Novel transportation methods are becoming increasingly common and are being adopted into regulatory regimes, which may theoretically speed up this process. Integration of these emerging modes as well as cars into public transportation networks, for instance, may improve mobility as well as contribute to modal changes away from personal automobiles. Micromobility can be analysed in the sense of entry and egress trips to and from public transit in order to determine the capacity for improvement. This revolutionary concept for movement within cities has drawn attention from the research community due to its positive prospects.

Several models of micro-vehicles have been introduced in the last few decades, both for shared as well as private usage, and have received a lot of positive feedback. Globally, for example, bicycle share services have grown exponentially, from 17 in 2005 to over 2900 in 2019 [26], as more hybrid bicycles coupled with pedelecs (power-assisted e-bike) become affordable. From 2010 onwards, dockless bike-sharing has risen in importance, beginning in China and quickly spreading across the world [27]. Similarly, e-scooter cooperation's including Lime and Bird started their first outlet in 2017 and has widen their coverage to hundred cities worldwide two years later, logging millions of journeys [28]. Voi (https://www.voiscooters.com/ride-safe/), an e-scooter business headquartered in Europe, has experienced similar success, spreading to ten countries within a year of launching [29].

Bicycles, e-bikes are all included in this definition and the list is by no means complete, and the authors recognise that the definition of micromobility is rapidly changing. As a result, the term "micromobility" has general connotations, as it is intended to be future-proof and therefore cannot be restricted to a specific automobile or power source. It can be used in this way to make new vehicle legislation easier and to establish a class that includes all micro-cars, regardless of car features. Nevertheless, for planners as well as politicians around the world, overseeing and enforcing policies that encourage and monitor usage of all modern automobiles is proving to be a difficult challenge. As a result, the International Transport Forum has proposed four classes of micro-vehicles according to their maximum velocity and weight, in order to better control the proliferation of micro-vehicles. "Safe micromobility" study contains further information on this concept as well as all categories of micro-vehicles and their classification [30]. And to better appreciate the global interest in the subject, Fig. 1 presents an overview of the micromobility publication trends. The figure emphasises the fact that micromobility related publications are growing over the years, with special focus on telecommunication systems associated with micromobility. Surprisingly, other seemingly important aspects such as energy, storage, heath impact, social impacts and environmental impacts were not covered properly, or the coverage lacked informed discussion of these issues. Interestingly the number of registered patents for micromobility solutions is high, indicating genuine interest. Moreover, the same pool of literature highlights the are many challenges facing micromobility implementation, and those are summarised in Fig. 2 [31–42].

Micromobility key advantage in a metropolitan context is to solve the first- and last-mile challenges by expanding networks to communal conveyance, hence increasing access to facilities and resources, as well as to contribute to improvements in commuting habits and behaviours targeted at less car-centric urban mobility networks [28]. One of the main objectives of this work is to present a robust overview of micromobility concepts and its adoption as medium of transport in urban areas. Also, an objective outlook on the progress made so far, and to reflect and evaluate aspects of micromobility that needs further attention, and synthesise the outcomes, primarily to explore the types of research that have been performed in relation to the topic. The bulk of the publications in this comprehensive literature analysis focuses on cycling and commuter sharing schemes. This is attributed to originality of other models of micro-vehicles, as well as a shortage of research about

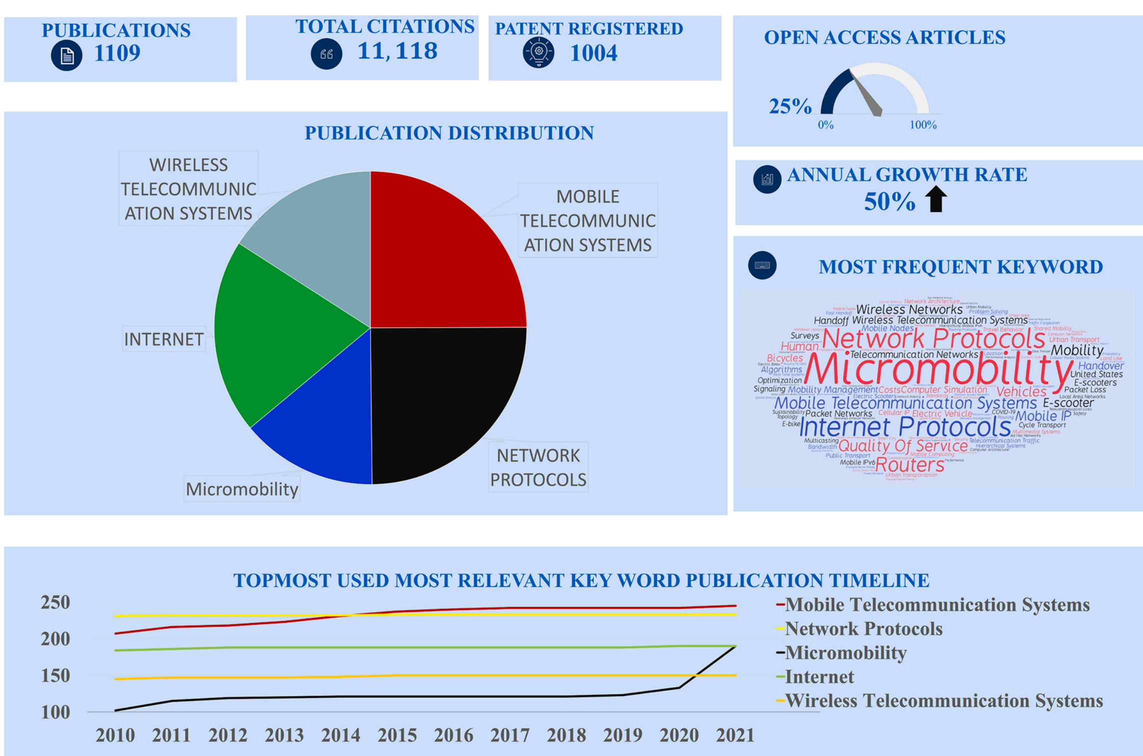


**Fig. 1.** Publication trend of micromobility publications from 2010 until 2021, self-extracted using from Scopus (www.scopus.com).

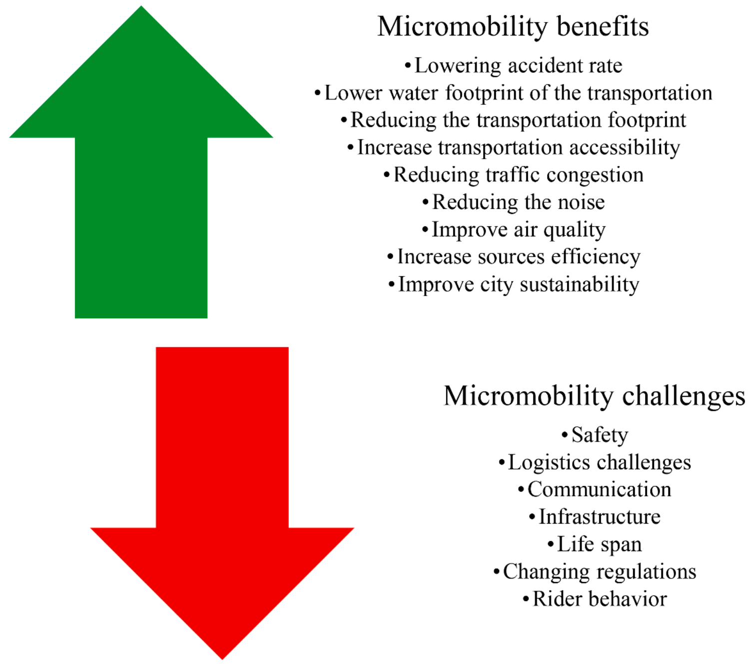


**Fig. 2.** Micromobility benefits and implementation challenges.

how they interact with other public transportation modes. When analysed in connection with public transit integrally, however, the results from this comprehensive literature review can include insights into related aspects and useful recommendations for the study of all forms of micro-vehicles. Moreover, governments, decision makers and different stockholder are looking the different transportation options to reduce the GHG and achieving the United Nation Sustainable Development Goals (SDGs), one these options is the micromobility. Therefore, the novelty here lies in that only few studies provided a detailed review on micromobility systems and to the best knowledge of the authors, no study has covered its role under the SDGs. As a result, this thorough research is an important addition to the ongoing discourse on micromobility.

This paper is structured as follows: First, an overview on available micromobility system, then micromobility role and relation to SDGs are discussed, followed by global policy options and proposals, then available standards for data, micromobility regulations, then a brief discussion of emerging technologies and micromobility utilisation determinants, and finally, a discussion on energy and energy storage of micromobility is given.

## 2. Description of micromobility and urban transit incorporation

When perceived as "hybrid, distinct travel mode" [43] and viewed as a single trip chain, the combination of micromobility and public transportation can be called a viable mode of transportation. This is when the benefits of both modes are expected to revolutionise the automotive industry. Scooters and E-bikes will further provide simplicity coupled with effective connectivity. Public transportation on the other hand has faster speeds, better governmental funding, robust supply chain and a larger geographic scope. Public transportation high speed and micromobility door-to-door usability produces a standard of access, velocity, as well as ease [43]. As a result, this mix increases the likelihood of modal changes and has the ability to lead significantly to more liveable neighbourhoods etc.

This emphasises the need to evaluate as well as research micromobility in the form of first- and last-mile connections in order to harness the maximum value for the move to more efficient urban mobility networks [28,29]. To completely exploit the capacity and synergies of the two types, designers, experts, micromobility and public transit suppliers, as well as concerned investors should consider them as two intertwined facets of the same scheme.

Micromobility and public transit convergence are two forms of mobility that can be accomplished in multiple ways, based on the facilities and resources accessible. To date, the key distinction of micromobility use has been utilizing public or private micro-vehicles. This mode of mobility, especially bicycles, have long been useful as medium of transportation. Shared micro-vehicle services, on the other hand, have grown in popularity in recent years and are now accessible in cities across the globe. These programmes have become more reliable and user-friendly as a result of technology advances and overall infrastructure upgrades, resulting in a competitive and appealing option for public transportation entry and egress journeys. Station-based and dock-less sharing networks are the two major categories of shared systems. Although users in a station-based units can only begin as well as end their journeys at predetermined places, users in a dock-less system can begin and end their trips (amongst) anywhere in the region. Many communities have begun to solve this problem by identifying unique areas where dock-less micro-vehicles may be stored owing to problems with parking in public spaces and on sidewalks.

## 3. E – powered micromobility

The last decade has seen a major transformation in terms urban micromobility. For most cities and urban communities the utilization of conventional vehicles is nearly impossible hence the need for eco – friendly, compact and light vehicles. The use of micromobility can aid in reduction in traffic jams, greenhouse gases as well as noise pollution. As the number of vehicles keep increasing appreciably, most community planners are exploring an effective approach in changing peoples mode of transport to lesser energy demanding modes such as walking, cycling etc. [44]. Electrically powered assisted personal mobility vehicles (e – PMVs) are considered as environmentally friendly means of transport for shorter trips in cities to help reduce traffic [45]. According to Zagorskas and Burinskiene [46], e – scooters are capable of replacing one percent of taxi trips in central city areas in the USA [46]. This therefore gives a critical indication that e – PMVs are capable of reducing the high dependence on cars for movement in cities. The main issue about e –

mobility is their cost for longer trips. This implies that though e – mobility is making significant difference in the automotive industry but for longer trips there is the need for an alternative approach using public transit. A pragmatic approach to resolve this is via the utilization of short connections to nearby transit stops. It must be noted that the usage of e – scooters in conjunction with transit is small because cost [47]. James et al. [48] argues that e – PMVs are gradually replacing commercial transportation, walking as well as cycling. Other studies conducted in Spain, Europe and other parts shows that the current state of e – PMV in these areas are increasing gradually. From Spain, the number of people using shared mobility at least twice in a week represents 3.5% of the entire country's population. There are still many more people often walking on foot (58%), travelling by public transport (53%), and using private cars (34%) [49]. The market for micromobility produced $3 billion in revenue in 2018 and is projected to reach $9.8 billion in 2025, growing at a 19.9% CAGR during the forecast period (2019–2025, Fig. 3). Due to the widespread usage of e-bikes and the affordability of this kind of transportation, the market is expanding. Micromobility is one of the many transportation options available when using light-duty vehicles, such bikes, scooters, and kick scooters as explained earlier. The majority of the time, these cars are used to travel small distances of five miles or less on a shared basis [50].

Some projects have also been made that the global PMV market comprising of scooters, walking aids, wheelchairs etc. are projected to grow at an annual growth rate of 7% [51]. These figures are very encouraging in terms of the future of some of these micromobilities. North American is current considered as the leading marking for PMVs. The second leading market for micromobility is Europe and this is 35% of PMV market value [52]. The evolutions of technology and IoT is currently changing the micromobility industry. Europe is currently facing a challenge where the evolution of technology is overly being consumed [53].

### 3.1. Types of E- mobility

An electric-powered small personal vehicle is known as an e-PMV. It is propelled by lithium-ion rechargeable batteries and has a range of 20 to 60 km/h. Currently, PMVs can be electric bicycles, electric scooters, monowheels, self-balancing vehicles, and other gadgets like electric skateboards as depicted in Fig. 4. E-PMVs are increasingly popular in metropolitan areas and are regularly utilised for short-distance travel. According to field observation collected in 2019 in numerous European cities, e-PMVs are as popular as or more popular than bicycles. They account for between 45 and 60 percent of all non-motorized and e-PMV traffic in the centres of Barcelona and Paris. Similar circumstances exist in places with public e-scooter sharing programmes that are less popular with visitors (Warsaw in Poland, Vilnius, Kaunas in Lithuania). It's unlikely that anything will change in the foreseeable future. E-PMVs now pose a serious threat to traditional bicycles because to advanced technology including more efficient electric motors, larger battery capacities, integrated computer processor units, and intense lighting. Future PMVs should be lightweight, small, easy to manage, safe to drive, and energy efficient. Another crucial factor is availability for sharing, which is made possible by GPS monitoring and the usage of smartphones [53].

Vehicles that use electric assistance or are entirely electric-powered can compete alongside professional athletes. The average power produced at cruising speed is between 100 and 160 W, while a regular cyclist is capable of producing up to 350 W of power. An athlete or someone who exercises regularly may produce two times as much power—an immediate 700–1000 W and an average 250–350 W. Modern e-bikes, e-scooters, and other similar vehicles typically add or function with power between 350 and 1000 W. The performance is less spectacular as a result of the motor and battery weight (5–15 kg), which adds up over time. The average trip speed is increased by at least two times with e-power assistance from a typical bicycle speed of 12 to 17 km/h to a 25 to 50 km/h e-motor pace [54]. Only the most robust gadgets with 750 W or more can reach a speed of 50 km/h. For safety purposes, the maximum speed is sometimes electrically controlled. The operating speed range and vehicle characteristics depicted in Fig. 4 highlight significant changes in mixed vehicle types. Three highly obvious speed zones were present in the past when walkers, bicyclists, and automobile traffic dominated the streets (4–7 km/h for pedestrians, 15–25 km/h for bicycle users, and 30–50 km/h for car users). As observed in the final column of Fig. 4, with the introduction of e-PMVs, these types of vehicles' operating speeds have progressively increased and are now comparable to those of automobile traffic. This has repercussions for sharing roadway space and raises the possibility of accidents.

In modern European towns, e-scooters are the most common electric vehicles [55]. Field observation statistics indicate that in certain cities, they have already surpassed regular bicycles in terms of popularity. One benefit of a leg-kick e-scooter is its compact size and the fact that many models can be folded, making it simple to transport one in a car or on

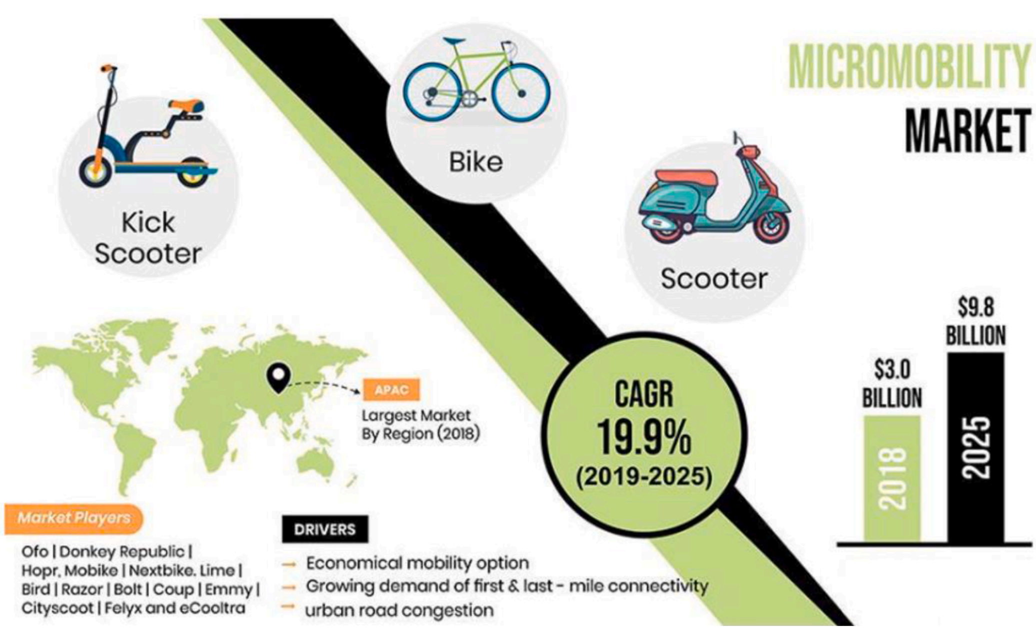


**Fig. 3.** Market growth of micromobility [50], open access.

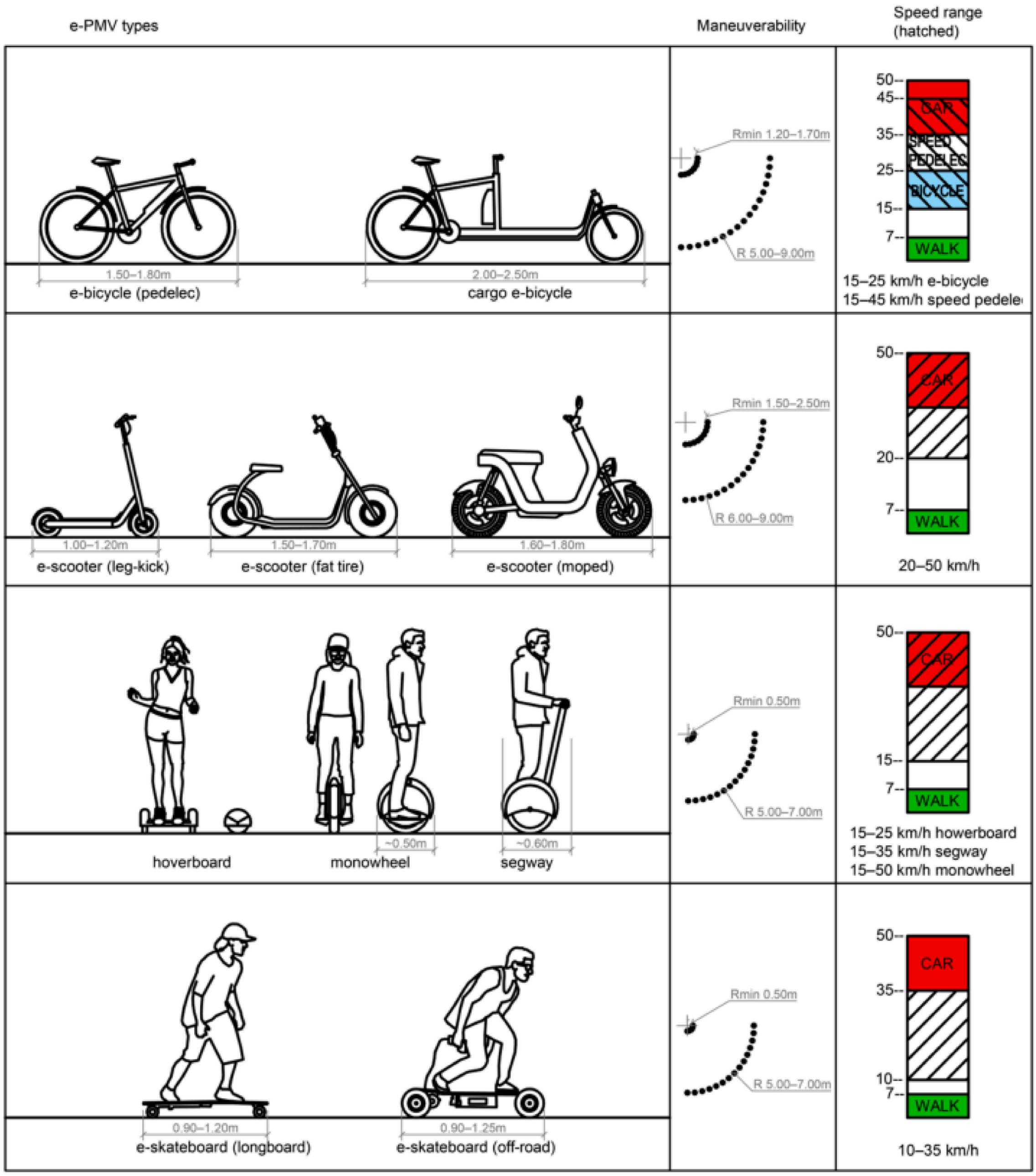


**Fig. 4.** Various Types of E – mobility [46], open access.

public transportation [56]. These scooters may be jumped on and off quickly and easily because of their standing posture, which also gives users the opportunity to carry out numerous everyday tasks while just standing on the scooter [57]. On the other hand, travelling faster on an e-scooter can be risky since an accident that occurs when the rider is standing up straight frequently causes severe damage to the hands and head. A "fat-tire" electric scooter can stand unaided on the road or go over difficult terrain thanks to its broad tyres. When compared to a leg-kick electric scooter, it is smoother, safer, and quieter to ride. Since their motors are often more powerful and their batteries are bigger, moped-style electric scooters can be categorised in the same category as mopeds powered by internal combustion engines and frequently share space with vehicles. Due to the need of a sitting posture and the requirement to wear a helmet, it may be said to be safer than an electric scooter with a leg kick.

With the development of a self-balancing mechanism, a variety of gadgets, beginning with the Segway released in 2001, started to emerge on the streets. Later, the same technology was added to several varieties of e-wheelers. The "hoverboard" and "monowheel" gadgets are now the most well-known e-wheelers. Children and teens like "hoverboard" vehicles, which are mostly used for amusement at playgrounds, parks, etc. The "monowheel" is renowned for its small size (it can be transported inside buildings and on public transportation in an ordinary backpack), fast speed (750 W-1 kW variants can travel up to 50 km/h) [46], and exceptional manoeuvrability. The more expensive pricing and the fact that it takes some time (often a few days) to learn how to use this gadget are its drawbacks. Many different recreational or athletic equipment types, including skateboards, are incorporating electric motors. Powered variants provide adjustments for a better ride on difficult terrain. These upgrades have larger inflatable wheels. They have a more powerful remote control that the user can typically use, either wirelessly or over wires.

*3.1.1. Micromobility and energy systems*

Many energy sources are passive, and although small in scale, but if harnessed appropriately can accumulate into a usable critical mass. For example, vibration-based energy transfer known as piezoelectric energy harvesting has number of benefits, including low initial investment and simple wiring. Piezoelectric power is described as a possible energy medium for small gadgets [58], and it can be a real solution for micromobility in large cities that has various sources of vibration resources. Many studies evaluate utilising piezoelectric materials to produce electricity on a larger scale, such as building a bikeway and pedestrian walkway. To achieve optimum harvested power, the correlation of piezoelectric materials coupled with conversion technique, resonance frequency, and physical parameters are taken into account [59]. Piezoelectric modules can produce electricity in two ways: by reaching or vibrating. The frequency must be balanced with the resonance to generate power via vibration, however additional instrumentation is needed to monitor and regulate the vibration characteristics to achieve resonance vibration. Since cycling is a low-frequency process, it is challenging to decrease the piezoelectric natural frequency reaching the cycling frequency [60,61].

Zhang et al. [62] introduce coils for vibration-energy harvesters dependant on electromagnetic energy transfer. Ali et al. [63] studied piezoelectric energy harvesting i.e., energies produced by muscle relaxing. Kulkarni et al. [64] demonstrated that piezoelectric energy harvesting can be used in automotive systems. Similarly, piezoelectric fuel injectors are more reliable. Chen et al. [65] looked at utilization of piezoelectric energy harvesting in buildings as well as reviewed piezoelectric components. Tang et al. [66] investigated piezoelectric in machining and suggested solution that used piezoelectric patches to increase the system's stability and efficiency. The electromechanical transfer properties of piezoelectrics were studied by Xu et al. [67]. Yang et al. [68] looked at piezoelectric systems with an emphasis on high-power performance and small operating bandwidth methodologies. Elhalwagy et al. [69] conducted a study of piezoelectric energy harvesting. Garimella et al. [70] address a system for producing electrical power from vibration, with the proposed method able to produce electricity from unnecessary vibrations. Laumann et al. [71] studied piezoelectric energy harvesting. Similarly, Yang et al. [72] performed measurements coupled on piezoelectric energy transfer. The model for piezoelectric vibration energy harvesting utilising polymer was examined by Wei and Jing [73]. Non-linear effects were explored by Zhang et al. [74]. Tran et al. [75] include evaluations on non-linear vibration control; additionally, Yildirim et al. [76] present the improvement technique required to transform ambient energy. By studying electrical properties under different bending conditions, Cao et al. [77] present transverse piezoelectric effects of polypropylene ferroelectric. To reflect the energy transfer process, Cao et al. [78] conducted the basic operating concepts of dipole moments polymers. According to other published data, there are actually fascinating renewable energy sources that can be utilised to harness atmospheric energy as well as convert it into functional electricity. As a result, in order to promote energy consumption in a balanced world, this investigation discusses the usage of piezoelectric content to accumulate energy from exercise. Installing energy harvesting devices made of piezoelectric materials on bike was used to test viability of harvesting power from workout device. The use of an exercise bike (Fig. 5) generates piezoelectric electricity, which is investigated in several studies from literature.

Usage of renewable energy or sustainable energy to boost power production is a highly studied subject since it can be used as domestic energy as well as income generation avenue; moreover, the issue on toxic emission is curbed as well as encourages wellbeing, which can have a direct effect on tourism industries and health tourism. Sun et al.

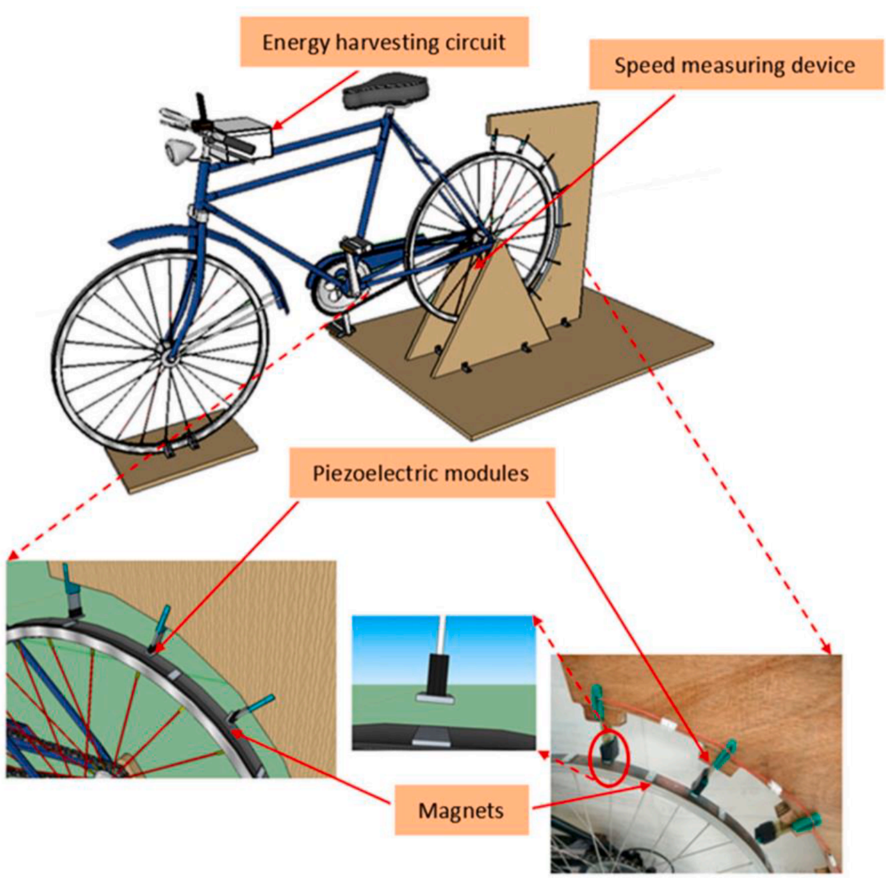


**Fig. 5.** A piezoelectric material is used to incorporate an energy storage device on an exercise bike [79], open access.

[80] investigated effects of power electronics on grid reliability in order to promote the energy agenda. Rahbar et al. [81] investigated incorporation as well as optimization of sustainable energy supplies and proposed algorithms useful in several microgrids. Du et al. [82] developed a concept and algorithm for improving solar power technologies as well as integrating it into the power system; the suggested strategy was more flexible to incorporate than variable renewable energy, resulting in the installation requiring fewer renewable resources. Zhou et al. [83] suggested ideal timing of multiple sustainable energy medium by examining multicarrier energy resources coupled with adapting the technique to microgrid; the recommended concept minimised charging of batteries and discharging activities while still confirming the potential to have a strong saturation of different sustainable medium of energy generation. Qazi et al. [84] reviewed the management of green energy sources in the power production sector, emphasising the importance of public sentiment. The optimal design for multi-renewable energy systems was researched by Huang et al. [85], who took into account load profiles, power costs, coupled with apparatus specifications to construct ideal systems; recommended solution was to improve both equipment collection as well as design. Cao et al. [86] investigated nanogenerators as self-powering machines and energy storage units capable of transforming mechanical - electrical power; the maximum power production was about 0.902 μW. This method will control electronic devices as well as a solid-state battery chip.

### *3.2. Micromobilty in smart cities*

A "smart city" by definition is one that is able to harness and convert energy seamlessly from one form to another, according to instantaneous needs of its inhabitants. For example, Lau et al. [61] applied multi-perspective data analysis to analyse Smart City implementations. Anjomshoaa et al. [87] proposed mobile sensing model for collecting data in Cambridge which will be useful in future development of micromobilities. To optimise data collection, this approach offers more benefits than traditional ways of gathering environmental data in metropolitan environments. Smart cities utilize smart systems that increase energy conservation and waste management practises. as Nizetic et al. concluded [88], The use of intelligent technology enabled by internet-of-things (IoT) concepts can stitch technological islands in one community, and demonstrates the importance of improvement opportunities, especially in the context of smart cities with encompasses micromobility. Ismagilova et al. [89] focused on the alignment of cities with United Nations Sustainable Development Priorities, based on existing Smart City concept shortcomings and emerging patterns. Smart cities strategic dimensions have received a lot of attention. Other novel concepts, such as Industry 4.0 as well as Smart Logistics was explored by Korczak and Kijewska [90] to allow an integral outlook and coordination of available technologies. The study highlighted that Smart Logistics aided in differentiating between mainstream as well as legislation of the development of the understanding of smart logistics. H. Haarstad and M. Wathna [91] investigate the links between Smart Cities and urban energy sustainability, as well as the viability of implementing one. They found that urbanisation might mask sustainability issues and misrepresent smart policies to promote economic development and creativity as energy sustainability policies.

In the context of the Smart City, Cellina et al. [92] conducted a study in Switzerland, investigating efficacy of modern intelligent technologies such as mobile applications that affect small power usage applications. Battarra et al. [93] used smart mobility to promote effective transportation etc. and they demonstrated that the transportation system's performance had increased as a result of this definition. According to Peprah et al. [94], Ghana a developing country in West Africa is yet to adopt the concept micromobility and this over the years has impacted the economy of the country negatively.

Lopez-Carreiro and Monzon investigated construction of efficient transportation networks [95], focused on determination of metrics for measuring urban mobility via called the Smart Mobility Index. Mobility managing procedure was recommended in Din et al. [96]'s research; the suggested plan provides consistent efficiency in terms of complete signalling. Finally, the Smart City model the latest solutions for increasing the country's productivity, improving social standards, modernising, and becoming a successful country.

Polypropylene ferroelectric (PPFE) was invented by Li et al. [97]. This is a lightweight, biocompatible unit. The finite element method for calculating mechanical–electrical energy transfer was introduced. Wan et al. [98] used inherently stretchable materials to demonstrate nanogenerator platform. The material is ideal for electronic units because of its performance reaction, different loading force, and frequency. Wang et al. [99] introduced an approach for energy harvesting using ferrofluid.

## 4. Policy options that encourage long-term micromobility results

Implementation coupled with feasibility trials of micromobility infrastructure have culminated into factors impeding their accelerated commercialization. Issues with protection, responsibility, operations, and facilities were among them [100]. The management of public utilities in metropolitan environments to improve mobility necessitates careful preparation as well as flexible legislation. Regulations and legislations for bike-friendly facilities, fleet maintenance practises, as well as progressive cultural participation, according to surveys undertaken in Sweden as well as Greece, are critical to the sustainability of successful municipal bike-sharing systems [101]. Pucher and Buehler [102] looked at the reasons for Canada's increased biking rates relative to the United States and discovered that rapid implementation of agile strategies based on successful promotion and protection improvement contributed to higher biking rates. Policy contexts for cycling, inexpensive fees, including GPS monitoring both helped to increase the chances of significant bike-sharing development [103].

### *4.1. Policies pertaining to the use of sidewalk space*

Policies for managing sidewalk and curb areas are critical for reducing clutter and accommodating micromobility, distribution systems, and pick-up and drop-off sites [93]. Formal mechanisms such as structured and codified rules, as well as mechanisms that facilitate pilot projects and agreed permits, are also part of successful sidewalk development strategies [104]. projects and agreed permits, are also part of successful sidewalk development strategies [93]. The following are key components of sidewalk control techniques for mutual micromobility:

- Unit caps: restricts the amount of automobiles on the road (bicycles, scooters, and other devices)
- Business area restrictions: places where service operations are permitted or forbidden
- Regular parking places: only these areas are used to park vehicles.
- Fees: monthly fees or taxes paid by the landlord for usage of public right-of-way spaces based on trip distance or time.
- Equipment including regulatory standards: regulations restricting administrative rates as well as permissible operating areas [105].

Finally, proper urban types and legislation are necessary to enable high-quality mobility while limiting trip lengths [106]. In 2018, Singapore passed the Active Mobility Act, which established rules for the secure sharing of public paths [107]. This act involved the implementation of road rules [107] with the goal of reducing collisions on public roads as well as routes [107]. Similarly, the United Kingdom adopted the first regulatory system for e-scooters, which included control of leasing scheme activities coupled with limiting the utilization of these machines to highways and bike lanes with a 15mph speed limit [108].

### 4.2. Quality expectations that are reasonable and services that promote equity

The following are some of the more common fields of equity interest [109]. Majority of mutual micromobility resources include payment by bank card. For users who may not have connections to these services, this becomes an obstacle. Appropriate financing methods, such as pre-paid cards and public transportation cards, must be weighed. These programmes can be prohibitively costly for low-income consumers. Discounts or discounts for qualifying low-income families may be considered. Non-tech alternatives, such as coin-deposit activities, can be addressed for people who may not have connections to a smartphone or mobile internet. Certain areas, such as suburbs farther away from the city or deprived populations, could be excluded from shared micromobility services. Modified vehicles, such as tricycles including hand-pedalled bikes, will also enable people with disabilities gain entry.

### 4.3. Ensuring the rules are followed

Enforcement is especially important in terms of safety concerns such as sidewalk decluttering and maintaining healthy pedestrian travel. The following are some of the more often used compliance policies [109]:

Mandating industrial businesses to evacuate machines that are clogging sidewalks and setting them a deadline to do so. This aids in the preservation of right-of-way access as well as general recognition.

### 4.4. Standards for data

Government departments should provide access to centralised and accessible data to support them appreciate effect of programmes, track fair conditions, as well as embed data into their processes and provide multimodal actual facts to travellers. There will be a need for guidelines for public bodies regarding how to implement transparent data practises for their micromobility policies. There are several of them [109]:

Knowledge about data gathering can be carried out as well as geocoded for mapping purposes is needed.

Guaranteeing the data is available in usable format that allows for download, indexing, and searchability, as well as being machine-readable.

- An open licence ensures that the data is accessible to the general public.
- Ensure that data quality is high, that it is appropriate, and that it is accessible as much as possible. Due to concerns over data ownership as well as safety, all data should be anonymized [110]. Protocols on how data is recorded, processed, and reported in a clear manner are often needed [111].

### 4.5. The importance of micromobility regulations

The aim of legislation is to facilitate the efficient utilisation micromobility technologies as a viable mode of transportation. This may provide different services around congested highways as well as intersections, and also traffic calming for suburban areas to improve protection as well as comfort [102]. Table 1 shows several illustrations of strategies designed to encourage micromobility [112]. A variety of measures, like that of the development of facilities for roadways with adequate parking, favourable land utilization, coupled with connectivity with public transportation, are required to enable broader adoptions [112]. Enhanced vehicle license charges, limits on automobile owners, as well as higher parking charges have also been implemented in the Netherlands, Denmark, and Germany [102,112]

**Table 1**
Overview of regulations to promote hybrid two-wheel mobility [112].

| Criteria | Measures |
|---|---|
| Rules | • Device rates have been reduced.<br>• Mandatory usage of protective helmets needs to be clarified.<br>• Speed restrictions on public routes have been must be in place.<br>• Standards for device protection.<br>• Private, industrial, including parcel delivery providers must also register their devices. |
| Forecasting | Micromobility vehicle lanes can be planned and preserved.<br>To alleviate traffic congestion, transport demand must be controlled.<br>Implementation of parking spaces that do not obstruct micromobility.<br>Enhancing the efficiency of electric bike-sharing stations. |
| Monetary | Households and corporations will benefit from government subsidies.<br>Subsidies and tax breaks for hybrid micromobility purchases<br>Accept road prices for costing per kilometre or unit of time, however reconsider gasoline taxes (petrol and diesel). |
| Public sensitization | Micromobility must be supported by government as well as business through public sensitization and creation of awareness on the viability of this novel medium of transport. |

## 5. Emerging technology

The increasing use of information technology, smart computing, artificial intelligence (AI), as well as data analytics has aided the growth of intelligent transport systems in cities worldwide [113–115]. Data obtained from collaborative programs, specifically, contains temporal and spatial dynamics that may aid in understanding human actions as well as the ramifications and shortcomings of these interventions. According to Creutzig, [116], a multimodal system allows various data sets to be integrated, allowing for diverse trip uses as well as methods including e-scooters coupled with bike-sharing to be used. Origins as well as routes, battery capacity, subscription service, coupled with weather details are among the other items gathered for every journey. By combining artificial intelligence as well as deep learning, this information may be utilised to improve potential technologies as well as facilities [117–119]. Artificial intelligence will also aid vehicle management, deployment optimization, including compatibility depending on customer requirements, ensuring that devices are distributed across the appropriate region [120].

Per research work conducted by de Chardon and Caruso [121], utilising publicly accessible station level information, emerging technology will automate bike-sharing use coupled with regulation of bicycle returns. The researchers determined regular ride-sharing trip estimates as well as identified spatio-temporal rebalancing bike amounts. Related research analysed large data to look at the spatiotemporal bike trends in Chicago [122]. Providers and politicians benefited from the knowledge derived from this data, such as maintenance specifications. Furthermore, these data may be used to determine where car parks can be located for most common sites [123] or to forecast demand at the stations stage [124]. Artificial intelligence will also help deter collisions by tracking route modifications, locating risks, including alerting vehicles [125]. Data was also utilized to analyse the effect of micromobility on the atmosphere, and also the effects of several other forms of transportation on commercial transportation transit times [126]. Via real-time analysis of the major elements of the connected system as well as making forecasts as to when adjustments are needed based on product maintenance schedules and user experience as well as reviews obtained from their smartphones, artificial intelligence and data-driven technology as well as sensors may also be useful for predictive maintenance [127].

## 6. Micromobility utilisation determinants

Micromobility systems' ability to improve access and accessibility to public transportation is one of their most enticing features. Comprehending public sentiment, attitudes, as well as issues concerning micromobility, as well as the socio-economic implications of transport modes preference, is critical for efficient micromobility service activity. In North America, a study of mode change to bike-sharing revealed that these programmes resulted in significant reductions in personal car as well as taxi usage, as well as the ability to attract riders from all other modes of transportation [128,129]. Attitudes including versatility etc. were discovered to have a significant impact on mode preference [130].

Mode preference as well as public approval are often influenced by urban area features such as topography and the number of cycling routes and sidewalks. The availability of sidewalks on the quickest distance to routes corresponds with a higher propensity to choose this style [130]. Cycling routes on curving territories reduce the appeal of active modes. Hilly plains were shown to be a major physical variable that influences the percentage of people who chose to bike to work in a related survey. The percentage of commuters who cycle is often influenced by road and weather conditions [131]. Furthermore, consumers respond differently to temperature fluctuations in various seasons as well as areas, so knowing the effects of environmental conditions in terms of seasonal and regional change is critical [132].

Initiatives like "Bike-to-Work-Day" were created to change people's minds about riding, resulting in increased commuter ownership as well as frequent utilization [133]. A variety of papers, including Heineke et al. [134], have looked at the factors that influence micromobility as a mode of transportation. Depending on 4000 web-based data collected from several Dutch municipality, it was discovered variables including a favourable outlook about cycling, the provision of bicycle storage facilities, the need to ride a bicycle through work time, as well as showering infrastructure are important and enhances the possibility of cycling to workplace. In other research, accessibility and cost benefits were identified to be the most important factors driving users' desires for bike-share [103]. Comparably, the plurality of urban citizens in the United States viewed sharing e-scooters favourably, with women as well as the lower income echelons of society showing marginally more interest [135]. In other experiments [136], higher average temperatures were shown to result in longer and quicker trips, although higher wind speeds resulted in shorter trips. Snow and rain, as predicted, had a negative impact on use.

A research in Indianapolis looked at the duration of e-scooter rides and discovered that fifteen percent of them were operated for more than an hour [137]. On Saturdays and Sundays, the time between 4 as well as 9 p.m. was established as the busiest timeframe for e-scooter use, with over 70 successful trips per minute. Weekends were the highest, over 150 successful trips every minute between 2 and 7 p.m. The spatial variation in scooter geo-fences was investigated in an Austrian analysis. Geo-fences and no-parking areas were found to be major obstacles for both riders and communities [138]. San Francisco launched a dockless electric bike-sharing scheme (JUMP) in 2018, in addition to an established station-based municipal bike-sharing system (Ford GoBike). JUMP's launch was discovered to have sparked novel interest in regions where docked facilities were unavailable [139]. A further research in Switzerland found that the distance spectrum for e-bike trips as well as taxi services coincided [140], indicating that they have the ability to interrupt car trips over short ranges.

## 7. Energy harnessing and energy storage for micromobility

An effective energy storage/conversion devices will play a significant role in the development of the micromobility. Although batteries are considered the most affordable energy storage systems that are being used effectively in several stationary and mobile devices [141–143], they are limited by the need of considerable time for recharge [144–146], have short life time [147,148], are sensitive to the surrounding temperature [149–151], and have environmental impacts [152–154]. Fuel cells demonstrated several merits compared to the batteries such as higher energy density [155–158], effectively employed in residential and transportation sectors [159,160], lower environmental impacts [8,161–163], operate effectively with renewable energy sources such as ethanol [164–167], methanol [167–170], urea [161, 171–174], and biomass in wastewater [175–178]. Furthermore, supercapacitor have higher long-term efficiency, higher power density, and higher lifetime than batteries [179–181]. Fuel cells and capacitors are effectively used in the renewable energy generation/storage systems [182,183]. Moreover, the solar powered station will lower micromobility footprint significantly and will contribute to the SDGs [184–187].

Harnessing energy from the sun is one of the viable medium of generating energy for various purposes. With the evolution and acceleration of micromobility in urban areas, energy from the sun can be harnessed to generate power at the doc station for e – scooters and bikes which will equally reduce the high dependence on battery powered devices. In Fig. 6 is a project by citibikes in New York where the solar panels supports locking and communication but not necessarily charging due to issues with space.

Spin has also developed another novel technology with the aid of concepts from Swiftmile. Scooters [189], shown Fig. 7 are now equally chargeable using energy from the sun. This is modular and flexible. Currently they come with 4 charging units at the bottom capable of chagrining nearly 8 e – scooters simultaneously. Charging of these bikes usually takes nearly 4 h to attain full capacity. Excess energy from the wind and other renewable energy source coupled be implemented but for now the focus and feasibility studies are limited to only solar energy.

### 7.1. Regenerative breaking

Others have also discussed regenerative breaking as a medium of storing energy but the issues about poorly designed controllers are primary factors not making it appealing to most end users from a technical point of view [190]. For most e-scooters the DC motor is coupled into a charging circuit whenever the regenerative brakes are turned on but because there is not lots of kinetic energy capture due to the weight of the scooter being light, the process is not that feasible. Similarly, the batteries are not able to charge fast coupled with the fact that the process becomes effective at solely higher speed [191].

### 7.2. Other energy storage options

Lithium-ion batteries and supercapacitors are both energy storage units ideal for micro mobility. Supercapacitors with the aid of a double layer capacitance and pseudocapacitance is able to store energy for later use [192]. The life cycle of supercapacitors is way higher than that of batteries [193]. The cycle life for battery is between 500 – 10,000 whiles supercapacitors is excess of 100,000 – 1000,000 averagely [190]. Fig. 8 shows the discharge time coupled with capacities for various types of energy storage as well. The Flow battery might be considered a rival to the lithium ion battery.

Lithium ion battery is one of the often used energy storage unit since they possess high energy density and low physical weight compared to other battery systems. The cost of these storage units have declined in recent times due to accelerated research activities in the area leading to the evolution of cheaper materials for the development of the technology [195]. Their capability in the delivery of higher currents makes them suitable for micromobility. The replacement of graphite in lithium ion batteries with silicon anodes has enhanced the batteries power capabilities significantly [196,197].

The energy storage units are susceptible to temperature conditions hence at extreme temperature conditions the performance of the battery if likely to be destroyed sometimes leading to explosion [198]. The process of maintaining a constant battery condition is also another challenge. The battery management system should constantly be checked to ensure the energy storage unit performs better at all times. Charge and discharge control, level of charge, cell balance etc. are all primary issues that should be well managed by the BMS. Fig. 9 shows the failure of e scooter due to heating.

**Fig. 6.** Solar powered doc station in New York [188], open access.

**Fig. 7.** Solar powered e – scooters by Swiftmile [189], open access.

### 7.3. Battery thermal management systems

The primary goal for thermal management systems for batteries (Li – ion) are to ensure they are maintained within specific operating temperature range in order to guarantee ideal operating temperatures and performance. It is also a safety requirement as well as ensures longevity [199,200]. When running batteries, the temperature must be kept within acceptable bounds, which is accomplished by dispersing the most heat that may be created [201]. Similarly, battery thermal management systems must have a few key qualities, such as high dependability, affordability, little parasitic power use, as well as ease of maintenance [202]. The produced heat in the battery is reduced to a manageable level by the use of battery cooling devices, such as BTMSs, which in turn regulate the operating temperature. According to the medium, cooling systems for batteries may be divided into three categories: liquid, air, and phase change material (PCM) cooling systems [203]. They can further be classified into active cooling as well as passive cooling systems [204]. There is equally the direct cooling couple with the indirect cooling subject to the power requirement. This section will discuss novel approach for external cooling units for batteries operating at elevated temperatures. These cooling systems heavily relies on air, liquid and PCM. It is recommended that the difference between the inlet and outlet temperature for the coolant is reduced in order to attain the best uniformity for the cell temperature but also reduce variation between the cell surface and the coolant temperatures. In the following parts a brief description of the various thermal management systems for the batteries which is the main energy storage system used in micromobility is introduced.

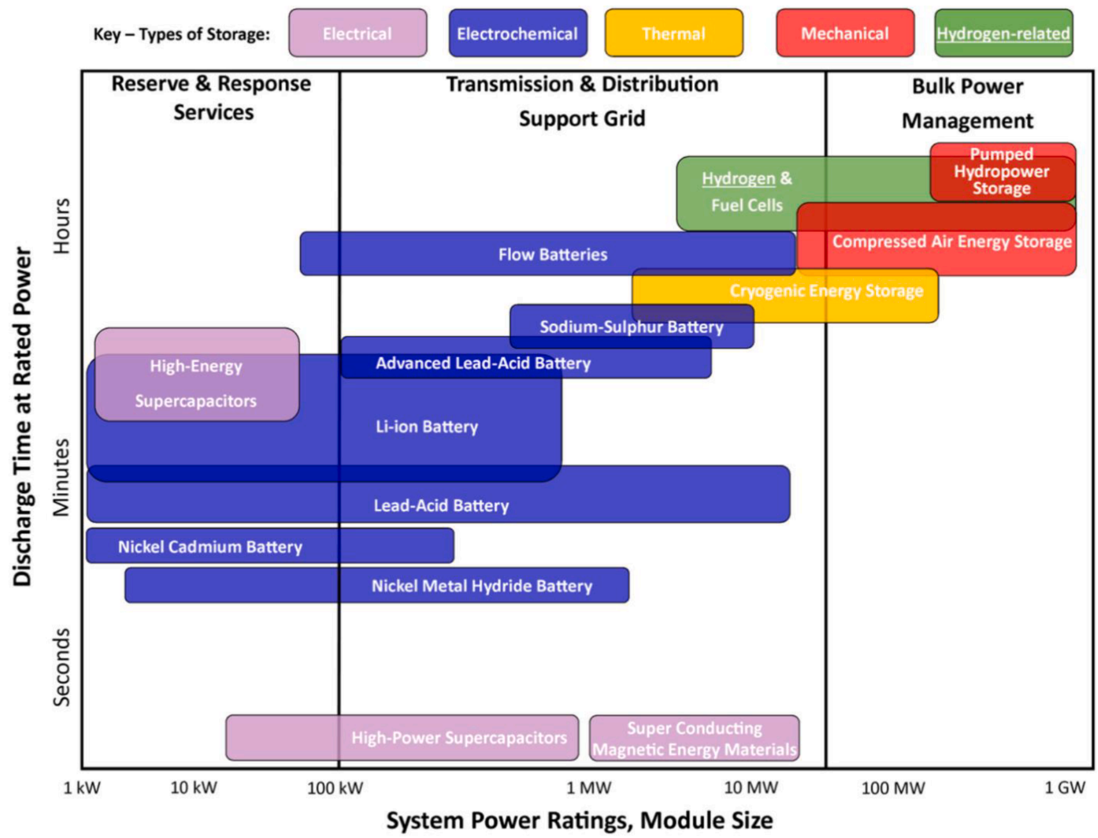


**Fig. 8.** Energy storage for different units [194], open access.

**Fig. 9.** Failure of energy storage unit in e –scooter [188], open access.

*7.3.1. Air cooling strategy*

Due to its numerous advantages, including their straightforward design, high dependability, low cost, and minimal maintenance requirements, air cooling systems are commonly utilised in BTMS [205, 206] . These cooling systems may be divided into two main categories: cooling that uses forced air and cooling that uses natural air. This study focuses on the cooling system that uses forced air since it has numerous benefits over the cooling system that employs natural cooling, including: Depending on a number of variables, including the battery module configuration, ambient temperature, cooling air temperature, flow rate, flow area, and airflow route length, forced air cooling can dramatically lower the overall battery module temperature [207]. The air cooling system's significant drawback, on the other hand, is poor thermal management, or an inadequate cooling impact. The thermal runaway occurs when the internal temperature of the battery pack rises over the operational temperature (about 55 °C) due to the high ambient temperature values in the range of 45 °C–50 °C. One of the most important factors that affects battery deterioration and cycle life is the uniformity of the temperature distribution, which is dependant on the flow rate [208]. The thermal performance of cylindrical batteries in various battery pack configurations was researched by Wang et al. [209]. The configurations that were looked at were 5 × 5, 3 × 8, and 1 × 24 arrays, 19 batteries arranged hexagonally, and 28 batteries arranged in a circle. Additionally, several air input and exhaust sites were researched. According to the findings, the battery pack's inlet and exhaust should be positioned at the top and bottom, respectively, for the best cooling performance. In terms of battery configurations, the cubic structure (5 × 5 array) delivers the best cooling within the battery pack while the hexagonal structure offers the best space usage. At the battery and pack level, unidirectional airflow often has low-temperature homogeneity. Batteries within the battery pack are heated or cooled differently depending on their proximity to the air intake or exhaust. This is caused by the air's capacity to absorb heat steadily declining as it absorbs heat from each battery individually. In comparison to the surface area at the leeward side, the windward side of the airflow interacts with a larger volume of air at the battery level. As a result, the battery's windward and

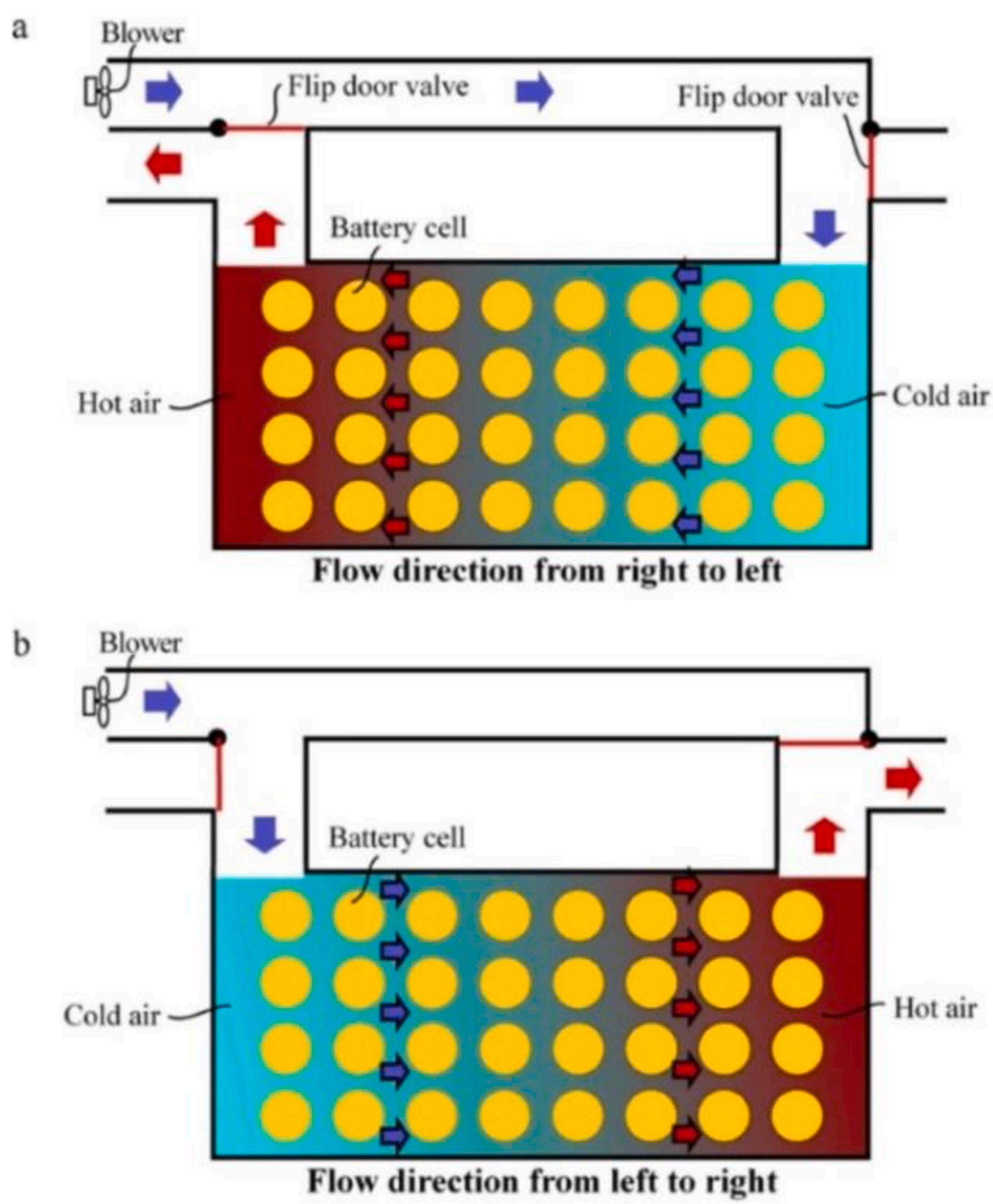


**Fig. 10.** Diagram for reciprocating battery thermal management system [210], permission to reproduce (License Number: 5473370058035).

leeward sides experience different temperatures. Mahamud and Park created and studied reciprocating airflow as a solution to this problem and to improve temperature uniformity [210]. The findings indicated that a reciprocating interval of 120 s is ideal for achieving a 4 °C temperature differential between the minimum and highest temperatures. In another parametric investigation on the reciprocating airflow, Liu et al. [211] found that for a temperature fluctuation of 3.76 °C, the air velocity should be 6 m/s, the reciprocation time 67.5 s, and the input temperature 10 °C. Reciprocating airflow has a problem, though, in that it is an active system and timing valves are included in the BTMS (as illustrated in Fig. 10), which makes the system more complex and causes low dependability and high costs [212].

#### 7.3.2. Liquid cooling strategy

There are two different BTMS liquid cooling methodologies: direct liquid cooling and indirect liquid cooling. A direct liquid cooling method holds the battery pack in an insulating coolant liquid that doesn't react chemically with any of the materials surrounding the cells, like mineral or silicone oils as examples, whereas an indirect liquid cooling method uses a liquid coolant, like deionized water, propylene glycol, or ethylene glycol, circulated around the battery pack or the tray on which the battery pack is mounted. Furthermore, because liquids are more viscous than air, the pumping power is significantly enhanced. Additionally, there is a substantial chance of liquid leakage, particularly with big battery packs. The indirect BTMS, in which the liquid is restrained within cool plates, was created to address these problems. The batteries are then brought into immediate contact with these cool plates. As it readily incorporates the rectangular shape of these batteries, cold plate utilisation is now applicable to prismatic and pouch batteries [213]. Additionally, Zhao et al. [214] examined cold plates for cylindrical batteries; however, due to the challenge of producing cylindrical cold plates, the complexity of the construction significantly increased. Tesla first devised a liquid cooling channel that snaked between the sides of the batteries, drawing heat from one side of the battery, to address this issue. They recently unveiled a tablet battery design for big cylindrical cells that has improved heat dissipation and reduced resistance. As a result, they can attach the batteries directly to the aluminium frame without having to create separate modules. In order to extract heat, the cold plates are now positioned at the top and bottom of the batteries. A liquid-cooled BTMS for cylindrical batteries was created by Rao et al. [215] utilising variable-length aluminium blocks for each battery. Fig. 11 displays the system's schematic. The liquid tubes passed between the metal blocks and along the length of the battery row. According to the findings, the temperature homogeneity rose by 6% for a 1 mm length rise, 14% for a 2 mm length increment, and 28% for a 3 mm length increment when compared to an aluminium block of uniform length.

#### 7.3.3. Phase change material cooling strategies

Materials that can release or absorb a certain amount of thermal energy during freezing and thawing processes, or phase changes, can be heated or cooled. PCMs emit a certain amount of thermal energy as latent heat of fusion or crystallisation energy during the freezing process [216–220]. In contrast, because PCMs absorb some thermal energy from their surroundings during the dissolving process in order to transition from the solid to the liquid phase, they may be effectively employed as a cooling method [221–223]. Powerful battery pack thermal management is achieved by PCM-based cooling systems because, in the case of a single battery cell failure, the PCM system responds quickly by dispersing the heat produced and preventing thermal runaway [224]. The most notable characteristics of the PCM cooling strategy are its high thermal conductivity and capacity to store heat. As shown in Fig. 12, PCM cooling systems fall under the category of passive cooling systems because they may act as a blanket for each Li-ion cell without the use of additional heat-transfer mechanisms [225]. The performance, safety, and size of the PCM cooling systems can be regarded as the best, but their cost, reliability, and energy consumption can be scored with the lowest grade when compared to the other exterior cooling systems. Last but not least, compared to other exterior cooling systems, PCM cooling systems can be characterised as having a medium weight.

#### 7.3.4. Hybrid battery thermal management systems

Researchers have introduced and created a hybrid method to get beyond the limitations imposed by pure air cooling or liquid cooling BTMS. Cold plates were positioned at the base of the cylindrical batteries by Wang et al. [226], while a fan is used to circulate the air within the battery pack housing as can be seen in Fig. 13. The configuration with the fan underneath the cold plate produced a flow field that was completely formed.

## 8. Micromobility role in sustainable development goals (SDGs)

The SDGs are set of 17 Goals set and developed by the United Nations, shown in Fig. 14, and were globally adopted by all most all the nations for the well being of the population [227]. The SDGs cover three dimensions of the sustainable development i.e., social, economic and environment. The SDGs implementation also provide a platform for different players in any industry to measure their contribution toward the sustainable development [228]. The micromobility has the potential to contribute toward the achievement of the SDGs. Fig. 15. Provides an overview of this role [38–42, 229,230]. The following sections will explain this role in detail.

Small, on-demand accessibility solutions such as shared bicycles [135,231] have exploded in popularity during the last decade. These

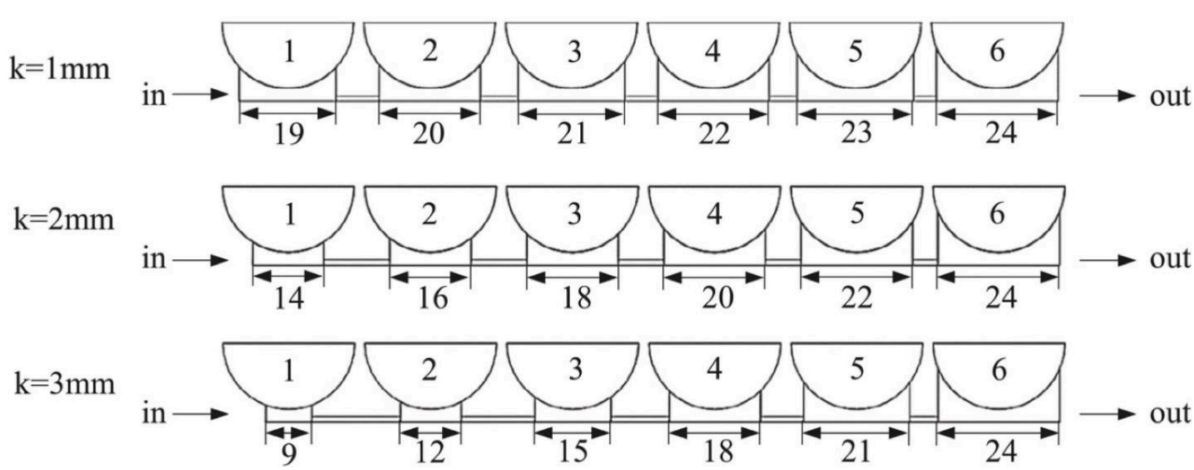


**Fig. 11.** Diagram of variable length aluminium block [215], permission to reproduce (License Number: 5473401384371).

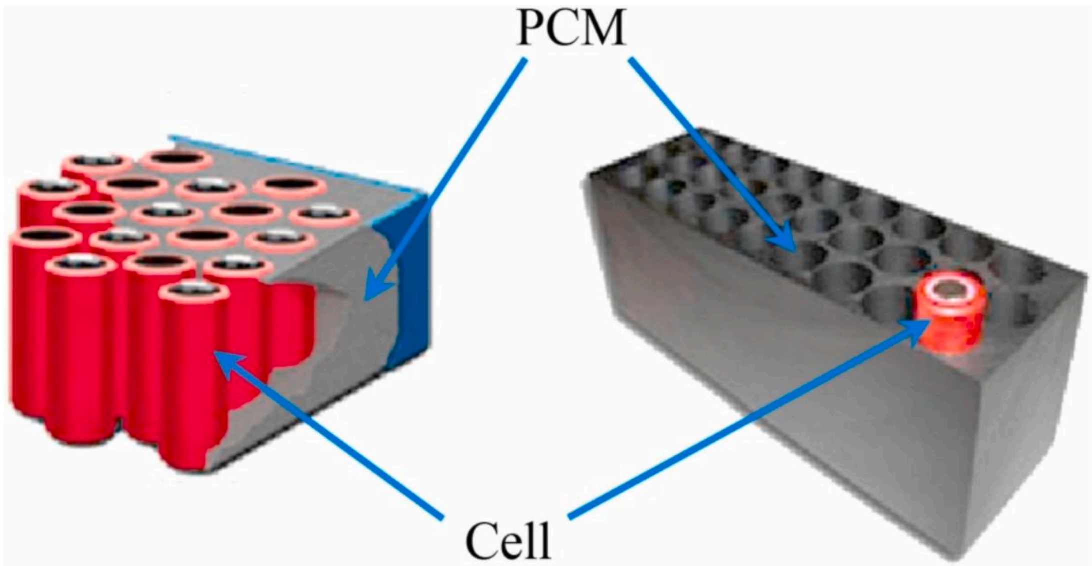


**Fig. 12.** Phase Change Material cooling unit [225], permission to reproduce (License Number: 5473420889766).

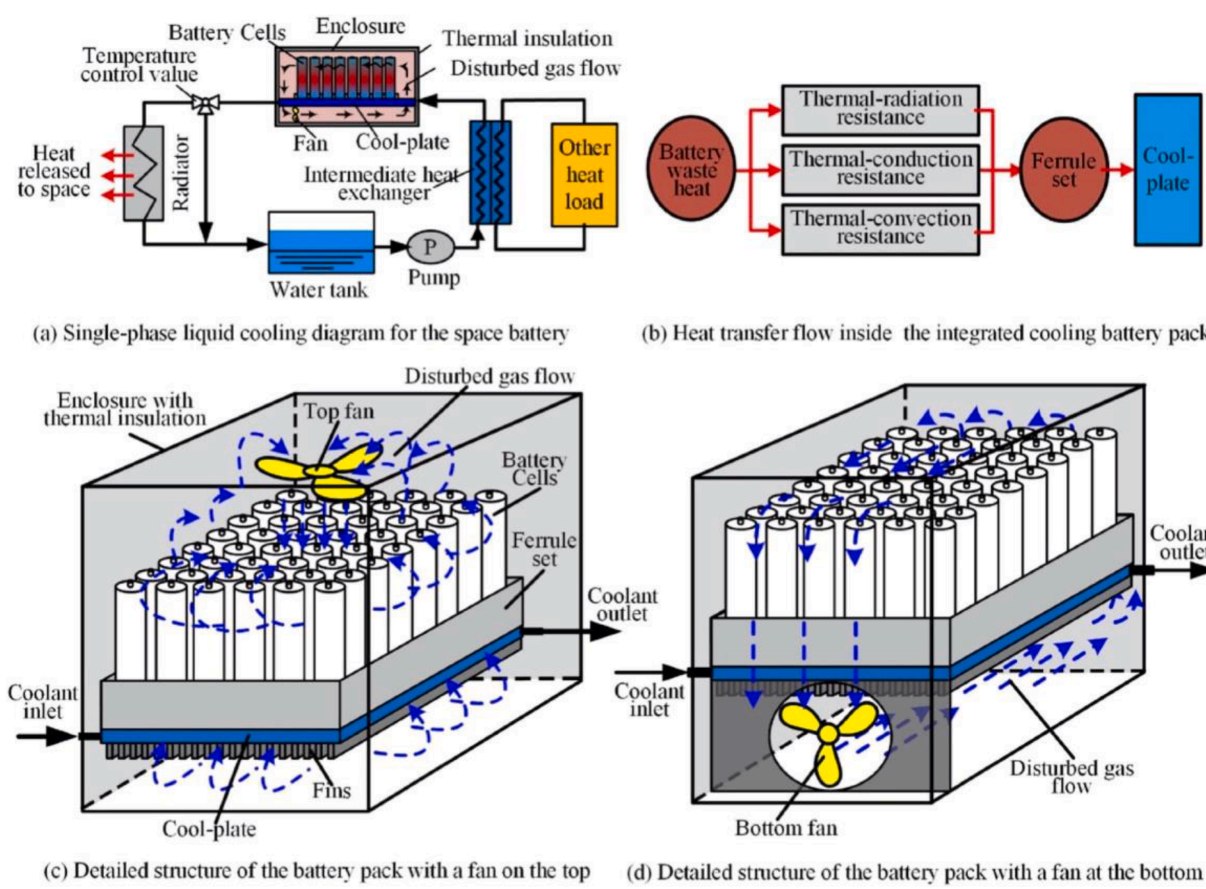


**Fig. 13.** Detail diagram for the PTMs using liquid cold Pilates [226], with permission to reproduce (License Number: 5473430345758).

modern modes, which are also referred to as micromobility, have the capacity to solve three dimensions of sustainability. Next, they can help to boost environmental sustainability by reducing dependency on private cars. They have further potential to solve economic mobility gaps by offering secure, affordable, and inclusive transportation that connects to public transportation and other types.

They are still in a good place to help communities become more integrated, and more resilient [232]. Micromobility forms, which include docked as well as dock-less e-scooters are described by some writers as tiny, lightweight vehicles [233]. This is because, owing to their novelty and accelerated evolution, sustainability information connected with these micromobility modes requires a systematic care, making it difficult to comprehend micromobility's general potential to promote sustainable transportation networks. Transportation planners,


**Fig. 14.** The United Nation Sustainable Development Goals (SDGs).

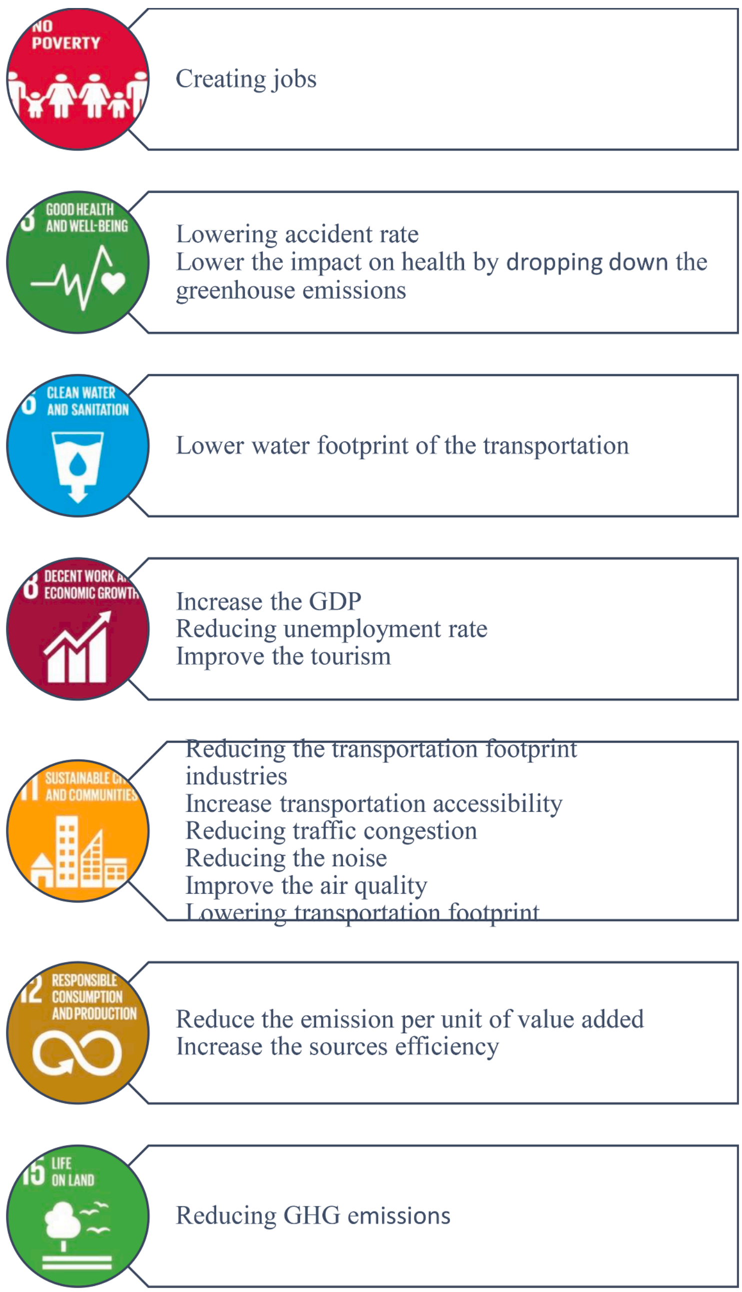


**Fig. 15.** The role of micromobility in the SDGs.

policymakers, and analysts would need a detailed sustainability image of micromobility to direct the intended usage of micromobility to improve transportation systems.

Many established mechanisms apply the Brundtland Report method of sustainable development—elaborated as "development that meets current needs without jeopardising future generations' capacity to fulfil their own needs" [139] — to sustainable transportation [234]. Successful models, according to Pei et al. [234], provide a systemic vision of sustainability. From early 2000s, the idea of sustainable transportation has been developing and progressing [232]. Sustainable transportation, according to Deakin [139], results in the release of less emissions as well as utilisation of non-renewable energy. Reduced car dependence or use [235,236] more efficient vehicle fleets, and prioritisation of transit, walking, coupled with cycling are key means of ensuring sustainable transportation become a reality [237–239].

To these measurements, Schiller and Kenworthy [240] apply the need to meet various economic and environmental targets, improve connectivity, and improve the liveability and human values of metropolitan areas. Sustainable transportation networks can, in this sense, efficiently link consumers to jobs and other resources while also lowering household transportation costs [241]. Transportation efficiency and sustainability can be balanced by public–private collaborations and user rewards or concessions [242]. For example, Deakin et al. [139] stresse the requirement of common access to sustainable transportation. Transportation-related equity priorities include a wide range of environmental issues. These include comprehensive, multimodal networks that offer connectivity to people [243], resource conservation that facilitate intergenerational transportation equality, as well as systems that meet consumer requirements independent of social, fiscal, or regional conditions [244,245]. Also, Tumlin et al. [246] considered many more complex topics, such as human personality. From the study, sustainability must strike a compromise between opposing goals. He also wants human feelings—inspiration, pleasure, belonging, joy, as well as beauty—to be included in this category. Using these concepts, they argue that long-term sustainable transportation infrastructure promotes mobility and connectivity through environmental, economic, and social factors. This strong definition of sustainability makes contingency preparation and trade-off analysis easier [246], rendering it adaptable to increasingly changing micromobility modes and their consequences. Based on the literature there are three fundamental aims that micromobility can meet to be deemed a sustainable mode of transportation [39,247–251]. However, these three fundamentals aim can be also linked to SDGs, as shown in Fig. 16. This will different players to understand linkage between micromobility sustainable fundamental and the SDGs will be achieved.

Micromobility would, first and foremost, eliminate toxic emissions from the automotive sector. This is done by motivating people to leave their vehicles at home and taking common transport or cycling to their destination. Then, using competitive market models and labour standards, micromobility can run efficiently and equitably whilst still promoting fairness and affordability initiatives. To include a way to outwardly measure success along these metrics, data exchange with municipalities is a critical component of this aim [252].

### 8.1. Reduction in greenhouse gas emissions

Since micromobility modes are powered manually, they have a lot of ability to mitigate GHG pollution via the replacement of car trips because of energy efficiency gains [253]. While micromobility trip distances vary depending on location couple with mode, the literature indicates that micromobility is ideally suited to replacing short trips [254–257]. According to a review of e-scooter travel in France, most trips were between 1.24 - 1.86 miles. The typical e-scooter ride in Washington, DC was 0.40 miles, while cycle shared trips were 1.62 miles averagely [258].

Nonautomobile modes will be viable for nearly 75 percent of city car trips based on these requirements. In London as well as New York City, a recent Uber-funded study predicted possible replacement impacts on car trips with sharing e-bikes [39]. In eight US towns, Kou et al. [259] looked into how station-based traditional bike share substituted cycling, mass transportation, and automobile rides. The plurality of trips substituted by bike share in each region is car trips, according to the authors.

McQueen, MacArthur, and Cherry [260] investigated the effects of converting a section of Portland, Oregon's mode share to private electric bikes. Utilizing current e-bike mileage substitution ratios discovered by MacArthur et al. [261] in North America, they noticed increment in e-bike mode share by Individual Miles Travelled (PMT) to 15% might minimise Portland's toxic emissions into the atmosphere from the automotive industry by 11%. Hollingsworth, Copeland, and Johnson [262] utilised Monte Carlo models to develop a number of e-scooter conditions and discovered that e-scooters frequently outperformed buses in terms of lifecycle emissions, owing to pollutants correlated with e-scooter collection, delivery, and limited lifetimes. The boundary conditions used in the investigations are depicted in Fig. 17 with the related SDGs.

However, where micromobility is used in combination with public transit instead than as a supplement, ability for micromobility to minimise toxic emission could be achieved. Micromobility, in contrast to cycling, will minimise the time and effort taken to enter transportation, thus extending transit's scope and increasing time competition with car journeys [255]. To this end, there is conflicting data that suggests travellers engage in micromobility as well as transit multimodal activity. Starting with the positives, 53% of survey respondents in Austin said dockless mobility made it simple or very easy to get about [263].

According to surveys conducted in three French towns, 15% of

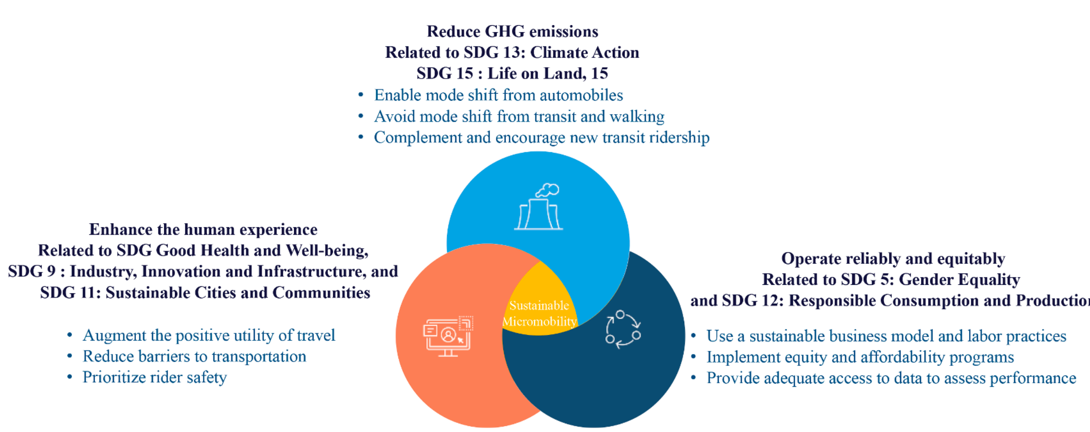


**Fig. 16.** Goals and frameworks for a sustainable micromobility architecture with relation to SDGs.

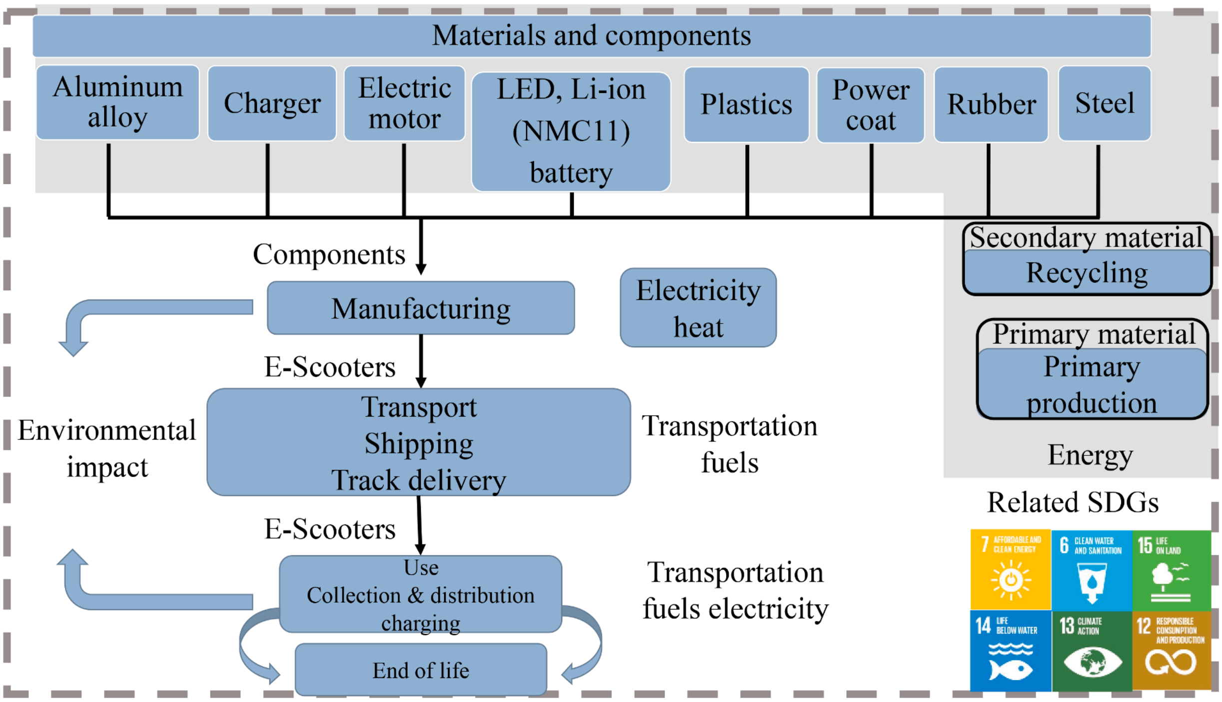


**Fig. 17.** A life cycle evaluation of cooperative dockless electric scooters using a system boundary diagram with the related SDGs.

respondents used an e-scooter and public transportation on their most recent ride [39]. In San Francisco, 34% of last-minute rides were to or from public transit [264]. In Santa Monica, on the other hand, just 4% of trips finished at the downtown light rail station, opposed to 13% at the beach and 28% in the downtown area [265]. A study showed existing commuting time and expense setting. The findings revealed that using an e-scooter paired with light rail was not superior to driving or biking directly [73]. These results show that there is still potential for progress in terms of encouraging people to utilise micromobility as a first-mile/last-mile. Generally speaking, the conflicting effects of multimodal activity throughout cities show that riders' willingness to pair e-scooters with transportation can be exclusive of e-scooter availability. Also, these disparities are due to the transit system's efficiency, frequency, as well as quality, although this needs to be investigated further.

### 8.2. Reliability coupled with equitability

Micromobility projects must be economically viable in order to serve as an equitable as well as efficient transportation alternative in the long run. Transportation is now an increasingly appealing sector for "policy entrepreneurs" [266], especially with the introduction of technological strategies that reduce the friction of utilizing public micromobility vehicles. Fortunately, striking a balance between the profit interest of private, sometimes international corporations and the broader service interests of transportation as a decentralised public utility has proven difficult. Few scientific papers have been released showing how joint micromobility commercial activities have failed or achieved in being economically viable. Seattle is a fascinating case study since it has a municipal bike sharing scheme as well as many independently owned and operated dockless e-bike share networks. As a result of insufficient system size, station density, regional service area, ease of usage, coupled with price structure, the city government - sponsored Pronto system failed [267]. These problems were not always caused by the fact that the scheme was dependant on stations. Rather, device architecture as well as business model decisions created a slew of problems. Pronto was gradually phased out in favour of commercial, dockless e-bike sharing services. In the first 16 weeks, these networks had more trips than Pronto did in its 2.5 years of service. For working in small communities, low-density zones, coupled with low-income neighbourhoods, shared micromobility networks face unique obstacles. Low use rates, higher public investment etc. were identified as risks contributing to failed bike share operations in Switzerland [268]. As a consequence, small communities could find themselves falling behind in the proliferation of micromobility solutions [269,270].

Labour expenses, in comparison to ridership as well as sales, have an effect on a company's economic viability. According to McKenzie [258], several novel micromobility firms have focused on comparatively cheap contractors to collect, charge, and sell micromobility vehicles (2019). A new California legislation, AB5, sought to restrict "gig economy" labour by further identifying who should be identified as sole consultant, disrupting this model. Due to this, micromobility firms in California have stopped recruiting independent contractors but instead started working with third-party employment agencies. Prior to the law's implementation, a Bird spokesman claimed that charging accounted for 40% of the company's operating costs [271]. Despite the high expense, reimbursement for chargers was extremely volatile [272], implying that working as an e-scooter charger is not a secure job. Micromobility companies have a hard time providing affordability as well as equity. A study of 44 American bike share providers found that half of them listed price or payment systems as deterrent to prospective riders [273]. The expense of operating an equity programme was listed by fifteen of these operators as a deterrent to reacting to these concerns. Others listed weak rail connectivity and a shortage of cycling facilities as obstacles to servicing those communities. Finally, some device operators suspected that some communities would be unable to enter due to the derogatory societal stigma correlated with bicycling. A sample of partners in bike share systems across US found that those in less populated areas were much less likely to be consciously trying to resolve equity issues [274]. However, equality schemes exist in 71–79 percent of the measured structures, including those that serve low-income individuals. Despite this, just 61% of these equity efforts provided a kind of data collection. Lack of financing was the most often mentioned impediment to bike share networks implementing equity programmes. Any communities have recently made it a part of operating licences for e-scooter firms to resolve equity issues. E-scooter providers were expected to deliver a fixed amount of e-scooters in under privileged communities to provide a low-income fare. Only one corporation, though, met the quota criteria, and only forty-three people were enroled in a low-income programme [275]. Similarly, involvement in e-scooter equity initiatives was poor in Santa Monica [265], prompting the city to propose that potential equity efforts could provide greater interaction with the populations that such programmes are meant to represent. San Francisco included equity provisions when reviewing e-scooter permit demands during the e-scooter pilot programme [276]. In their initiatives, vendors addressed issues from a range of viewpoints, like 50% off rides for social assistance recipients. Each corporation that was granted permit pledged to develop 20% of their fleet accessible in urban areas-designated high-risk areas. Again, real enrolment in the e-scooter equity initiative was limited [264].

Cities require access to micromobility data detailing spatiotemporal source coupled with demand, usage expense, rebalancing activities, user demographics as well as equity programme participation, collisions, and vehicle cycle life in order to consistently assess availability, efficiency, equity, and environmental results associated with micromobility. Cities have had difficulty entering into data exchange arrangements because this knowledge is deemed confidential by private companies. As part of 4-month e-scooter test programme, Portland introduced data exchange standards and sought details on e-scooter availability etc. However, owing to a lack of universally specified terminology, businesses' compliance with data collection standards differed, and complaint data processing did not fulfil Portland's expectations [275].

### 8.3. Enhancement of human experiences

Micromobility can, in particular, encourage transportation equality and connectivity, as well as health and protection, as well as pleasure. These considerations play a role in repetitive mode selection decisions [277]. Micromobility modes may significantly alter habitual travel behaviour if they are enjoyable, safe, and socially equitable. Electrified micromobility medium example e-bikes, e-bike sharing, and e-scooters are thought to be fun modes of transportation. According to a French poll, 69% of e-scooter consumers thought it was a pleasurable and enjoyable means of transportation [278]. A plurality (77%) of respondents to a North American e-bike survey said they use e-bike because it is more enjoyable to use compared to regular bike [279]. Furthermore, e-bikes draw potential markets by improving perceived protection and enjoyment of biking, and they may assist cyclists with physical disabilities. Micromobility modes may also help users overcome obstacles. In France, respondents said e-scooters save time [278]. E-bikes excel in allowing riders to pedal more often and over longer distances than traditional bicycle journeys [280]. They often make it easier to overcome difficult terrain [280]. Likewise, as opposed to traditional ride share riders, users of shared e-bike networks are less vulnerable to lengthy trips, low quality air etc. [281].

With the rise in recognition of micromobility, risk that pedestrian-friendly areas will be seen as less available becomes a major concern. Some communities mandate e-scooter businesses to restrict the places where their automobiles can ride at high pace, at all, or be stationed utilising a geofence scheme as one option [282]. This was used to effectively reduce e-scooter utilization in high-traffic places [283]. This technique will make it easier to find parking in places that are intended for commuters. The press has consistently emphasised the risk of dockless micromobility posing a threat to disabled users due to improper parking. In this vein, a focus group in Portland discovered that poorly parked e-scooters affected people with visual losses [275]. However, according to the literature, the true prevalence of illegal parking might be exaggerated. In San Jose, an assessment of e-scooter space showed that 2% of e-scooters were parked in a manner that impeded sidewalk movement [284]. Just 6% of parking e-scooters in Washington, DC blocked pedestrian right of way, according to James et al. [285]. Finally, Brown et al. [286] utilised parking audits in 5 American communities to discover that motor vehicles (24.7%) obstruct access more often than bicycles (0.3%) and e-scooters (0.3%). (1.7 percent). Micromobility has been well received in other vulnerable and underserved populations. Low-income groups have a favourable perception of e-scooters, according to a poll of 7000 Americans [135]. E-scooters were also seen favourably by far more women than men, indicating that they have the ability to reach greater gender balance than bike share. In Portland, 74 percent of Black Portlanders surveyed showed interest in and encouragement for e-scooters [275]. Over the 120-day pilot era, e-scooters were utilised to in a transportation-challenged part of cities, resulting in more than 44,000 rides. In this area, the total trip distance was greater than in the central region. Other e-scooter utilisation data, on the other hand, say a different tale. E-scooter operators in Santa Monica were more likely to be higher-income (47%) and younger (64%) than those in other cities [265]. There is a strong divide between those who have a favourable opinion about e-scooters and those who do utilize them. In Chicago, Philadelphia, and New York, low-income neighbourhoods of colour have expressed support for bike sharing [261]. By compared bike share riders to personal riders in Washington, DC, sharing of bikes were common practice amongst younger female, smaller household salaries, possess less vehicles and motorcycles, and ride for practical reasons [287,288]. Nonetheless, results in 2018 indicate that CaBi consumers are still more male compared to female [289]. Although its direct effect on the activities of micromobility firms, there are diverse outcomes when it comes to availability as a significant obstacle to micromobility use. 24 percent of French survey respondents said they often forego rent out of an e-scooter since none are accessible nearby [278]. However, in the Austin report, availability was ranked last as perceived option for encouraging people to use dockless mobility [263]. McQueen [242] discovered that, assuming all other factors remained constant, reducing the time taken to get into an e-scooter for combination e-scooter and light rail ride to downtown Portland did not render it superior to bike or vehicle modes. A study of Seattle's 2nd micromobility iteration, which included dockless e-cycle sharing schemes, discovered that areas with more per capita bike availability often had more college educated people, local government services, and higher incomes [290]. The inequities were defined as minor, and authors found no major access inequalities or gentrification-related housing displacement danger within communities of different racial/ethnic makeup. It's odd that these income inequities didn't lead to racial inequities, but it's likely that the aggregate of community characteristics masked racial inequities that might have been visible if user access profiles had been included.

In comparison to accessibility of micromobility modes, the report more specifically recognises expense coupled with accessibility challenges that overwhelmingly affect low-income and minority populations [274]. Equitable expense and discount structuring, as well as unbanked-friendly payment systems, have been used as alternatives to these hurdles [273]. Racism on both a systemic and person level can deter these users from taking advantage of micromobility. Though the passion for e-scooters in Portland [275], the black Portlanders raised concerns about possibility of racial discrimination and intimidation when riding them [275]. Others [291] discovered that places with less educated, lower social status, coupled with a higher Hispanic areas have slightly less bike lanes. As a result, greater attempts to remedy the drawbacks and oppression of persons of colour and other disadvantaged populations would only boost micromobility transportation results.

Current safety risks posed by micromobility might restrict how much micromobility improves the human experience, since these risks will dampen sense of happiness connected with micromobility modes. Trivedi et al. [292] found that ride share and e-scooter riders should not use helmets. After the cost, the sensation of not being protected was the second popular notion for not riding an e-scooter in France. In an e-scooter accident in Austin, TX, a third of interviewees were hospitalised during their first outing [293]. Fractures, head trauma, contusions, sprains, as well as lacerations have all been recorded in e-scooter users [292]. It's likely that, close to parking problems, the media has exaggerated the cumulative safety dangers of micromobility. During the first e-scooter experiment, there were 176 urgent care accidents in Multnomah County [275]. Over the same time frame, the overall amount of visits was smaller than bicycle visits. According to another investigation on e-bike users, 80% of e-bike users have never been in an accident. Just 19 percent of those who did experience an accident thought their e-bike played a major role. More than half of the crashes recorded resulting in no or minor injuries [279].

### 8.4. Micromobility and sustainable city

SDG 11 is focusing making cities more safe, resilient and sustainable. The micromobility could play a significant role in achieving this role. In particularly the micromobility play key role in attaining Two Targets of SDG 11 i.e., Target 11.2: "provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety" and Target 11.6: "reduce the adverse per capita environmental impact of cities". Fig. 18 provides summary of this role.

## 9. Recommendations

To ensure that micromobility supports in the achievement of SDGs, the following measures need to be taken into considerations critically. Firstly, there will be the need for lowering the prices and increase availability of micromobility within the urban and rural area. Again, there will be the need to increase utilization of recent advanced medium of energy harnessing, renewable energy technologies, and energy storage within the micromobility industry. Government across the globe must do well in increasing incentives to attract investors to this growing sector. There is also urgent need for the incorporation of design for sustainability principles within the development of micromobility. Furthermore, all stakeholders must be considered during the process of developing new policies as well as regulations related to micromobility. Services rendered in relation to micromobility must also be equitable and affordable. Another critical recommendation is the incorporation of micromobility in training for road users and other stakeholders. The need for a more robust system in the capturing and analysing of data will be critical in the accelerated development of micromobility. Standardization of the data collection methods will help to further explore current issues within the micromobility industry and will help scientific community to evaluate new method to achieve sustainability within the micromobility sector.

## 10. Conclusions and future prospects

Cities throughout the world have been focusing on developing a more sustainable urban transportation system with the goal of delivering a well-connected, seamless mobility experience while reducing traffic, noise, and pollution. Despite all of the careful planning by government authorities, the growth of micromobility has been an unexpected, grassroots success story in the urban transportation industry in recent years. Thousands of users are taking use of an expanding range of shared micromobility choices in cities across Europe, the United States, and Asia. Micromobility and e-scooters are gaining popularity at an unprecedented rate. Hence this study aims to understand and review the overall system of micromobility, their role in Sustainable Development Goals (SDGs), the different policy and regulations available, challenges and utilisation determinants of micromobility, the emerging technology, and the energy and energy storage of micromobility.

This study has demonstrated that micromobility can play a major role in achieving the Sustainable Development Goals (SDGs). This contribution manifests in many different facets of the application, such as job creation (SDG 1: No Poverty), accident rate reduction, improving human health via reducing greenhouse gas emissions (SDG 3: Good Health and Well-being), decreasing water footprint (SDG 6: Clean Water and Sanitation), enhancing the economy, cutting the unemployment rate, improving the tourism industry (SDG 8: Decent Work and Economic Growth), lessening footprint reduction, improving accessibility to transportation, reducing the traffic congestion, improve the quality of the air (SDG 11: Sustainable Cities and Communities), decreasing emissions per unit of added value (SDG 12: Responsible Consumption and Production) and lowering the GHG emissions (SDG 13: Climate Action, SDG 15: Life on Land). However, to expand this contribution, many challenges, such as safety, logistics and rider behaviour, should be overcome. Moreover, there has been little discussion about energy source of micromobility station, where the renewable energy could be used to charge the micromobility.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

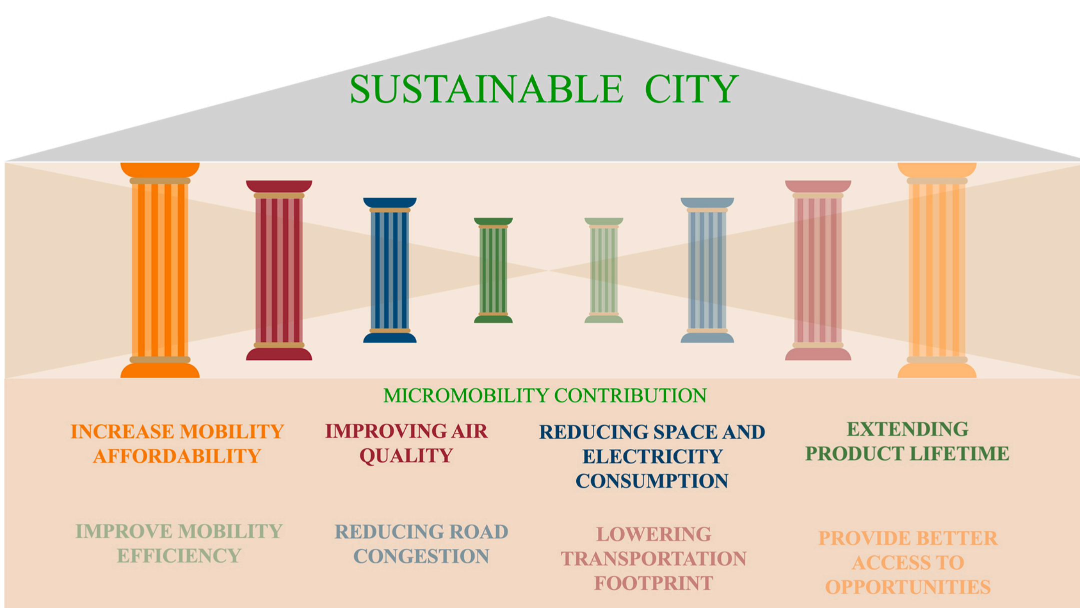


**Fig. 18.** Role of micromobility in a sustainable city.

the work reported in this paper.

## Data availability

No data was used for the research described in the article.

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