MICROMOBILITY: A SYSTEMATIC LITERATURE REVIEW ON THE MEASUREMENT OF ITS ENVIRONMENTAL, SOCIAL, AND ECONOMIC IMPACTS ON URBAN SUSTAINABILITY

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The use of micromobility in cities has been highly associated with environmental, social, and economic benefits. These sustainability impacts can be achieved by the proper city planning before the implementation of micro vehicles, which can include pilot programs, connection to public transport to promote first-and-last mile trips, curb space management, and safety measurements. Although to better understand the real environmental, social, and economic impacts of micromobility usage in cities, some methodologies need to be used in order to measure them. Thus, this research focuses on an extensive literature review to discuss the most used methodologies to measure the sustainability impacts generated in cities by micromobility. As the results show, to measure the environmental impacts, the Life Cycle Assessment methodology can be used, followed by geospatial analysis and surveys to measure the social impacts, and conversion of health, and time-saving benefits to a monetary unit to measure the economic impacts of micro vehicles.

1. INTRODUCTION

Micromobility is defined as a small mode of transport that is fully or partially human-powered, such as station-based bike-share (including e-bikes), dockless bike-share (including e-bikes), and scooter share (NACTO, 2019). One of the motivations to use micromobility in its shared version is to provide economic benefits to users, such as travel cost savings, facilitating access to resources, and free-riding (Hamari et al., 2015). On the other hand, the use of shared micromobility is usually expected to be highly ecologically sustainable (Prothero et al., 2011). Shared micromobility is also suggested to be used to foster a sustainable marketplace (Phipps et al., 2013) that "optimizes the environmental, social, and economic consequences of consumption to meet the needs of both current and future generations" (Luchs et al., 2011, p. 2).

As a means to promote sustainable urban mobility, micromobility trends are rapidly adapting (Six, 2019). Starting with bike-sharing systems, which were one of the fastest-growing transport innovations in many cities (Shaheen et al., 2020) and today counts with more than 855 systems worldwide in a variety of forms, such as dock-based systems, dockless or GPS-based systems, low-cost systems and peer-to-peer bike-sharing (Shared-Use Mobility Center, 2015). Until more recently, with the advent of shared e-scooters that emerged in 2017 in the United States, and in 2018 in Europe.

In the urban environment, micromobility should be incorporated in a city's planning process since it can support smart growth strategies in comprehensive mobility plans that encourage densification and development of areas that are poorly served by public transport, this smart growth provides transport choices that support first-and-last mile connections and give people sustainable mobility options (Cohen & Shaheen, 2016). Also, the incorporation of shared micromobility into subarea plans helps planners reimagine an automobile-centred city or suburb by providing innovative and financially sustainable mobility options integrated with traditional public transport (Cohen & Shaheen, 2016; Shared-Use Mobility Center, 2015).

The usage of micromobility as a first-and-last mile option in cities can contribute to the decrease in air pollution (Shaheen et al., 2010). In many cities around the world, such as Sydney and Melbourne short trips involve private cars, likewise in the United States, where more than half of the private car trips are used to travel less than eight kilometres (Abduljabbar et al., 2021). In these cases, micromobility has the potential to promote a modal shift from pollutant modes of transport to low-emission options, such as bicycles and e-scooters (Woods, 2019).

Besides the environmental impacts, the use of micromobility is also intended to help decrease equity problems in transport usage and provide economic benefits for users. The use of bicycles, e-scooters, and their shared version can be an asset to reduce transport social inequality, mainly when comparing men's and women's participation in urban displacements, as well as contribute to a higher distribution of transport accessibility in remote areas and provide money savings for users if compared to ridership of private cars (Dias et al., 2021).

To evaluate and measure the sustainability of micromobility in urban areas, a set of methodologies have been proposed by literature, such as Life Cycle Assessments (LCA) to study the environmental benefits of investing in these transport options to cities, as well as geospatial analysis that explores the equitable distribution of the services to the population in need (e.g., people in low-income people and marginalized parts of the population).

Thus, this research work aims at exploring how sustainability is measured for micromobility, describing how the most common methodologies are used to evaluate environmental, social, and economic sustainability for these modes of transport. For this, an extensive literature review is made to gather and explore the methodologies and discuss their application when assessing how micromobility can contribute to urban sustainability.

2. Sustainability in micromobility

2.1 Planning for sustainable micromobility

According to Cardell & Moller (2020), micromobility modes are sustainable and efficient for cities, presenting environmental benefits, moreover, their use must replace car trips instead of walking, for example. Also, cities must embrace infrastructure that encourages micromobility, as bicycles and e-scooters cannot just be thrown all over the city.

To avoid misplacement of micromobility modes and the disruption of the sustainability that can be achieved by their usage, some planning strategies can be used to influence positively the outcomes from bicycles and e-scooters in cities. The challenges and opportunities for planning micromobility and shared micromobility (National League of Cities, 2019) start from safety concerns, going through curb space management, firs-and-last mile usage, until pilot programs (Figure 1).

Safety	Curb space management	First-and-last mile	Pilot programs
• Human behavioral factors • Adequate infrastructure to accommodate micromobility	• Creation of designed parking zones for micromobility • Requirement of parking in designed parking	• Connection to public transport • Potential to increase the walking area of influence	•Test of microvehicles on smaller scale •Understanding of how micromobility fits existing mobility ecosystem

Figure 1: Challenges and opportunities for planning micromobility
Source: (National League of Cities, 2019)

The above challenges and opportunities brought to cities by the implementation of micromobility and shared micromobility can have the effect of changing the traditional planning paradigm of thinking the city for cars. Micromobility can stimulate the introduction of integrated and sustainable planning and new design in cities to make journeys more efficient for people who need or want to combine public transport with another option that can take them to their doorstep, without the need of having a car to do so.

In addition, the implementation of micromobility planning tools in cities is largely related to the improvement of urban air quality and reduction of climate changes (environmental footprint), as well as the provision of convenient and flexible transport for citizens and tourists (efficient mobility), and to get people out of their cars. On the other hand, some challenges related to the implementation of micromobility is cites is the modal shift (if micromobility only takes people from walking), visual pollution (people do not care where they park the micro vehicles), and the lack of proper infrastructure (Holm Moller & Simlett, 2020).

2.2 The power of micromobility to promote sustainability

As long as micromobility is considered a human-powered or electric light vehicle, it has a great potential to reduce greenhouse gas emissions, mainly if they are used to replace car trips, which can occur in short-distance displacements (Mason et al., 2015). When implemented, shared micromobility systems (e.g., bike-sharing) have shown an immediate impact in avoiding fuel usage and carbon emissions, as an example, in 2013, Denver B-Cycle users spared the atmosphere more than 460,000 kg of CO2 emissions and rode about 900,000 km (Gardner & Gaegauf, 2014).

An assessment performed by Cazzola & Crist (2020) shows that, when the estimates of life-cycle greenhouse gas emissions of urban transport modes per passenger per km are made and compared among urban vehicles, micromobility options, such as shared bicycles, shared e-bikes, and shared e-scooters have a smaller impact on CO2 emissions than public transport (e.g., buses) and a significant reduction on CO2 emissions if compared to private cars, ride-sourcing, and taxis.

In addition to its environmental benefits, micromobility can also act as a tool to promote social benefits in transport usage in cities. Even though sometimes shared micromobility systems can be seen as an expensive mode of transport, added to the fact that most companies providing the service require the users to have access to smartphones and credit cards to rent the vehicles, some measures can be taken to expand usage among more vulnerable users(McQueen et al., 2021). In the pilot program of shared e-scooter systems in Chicago, US, companies that were granted the rights to explore the shared e-scooter systems in the city were required to offer the service in more remote areas, and to introduce social discounts for low-income people, as well as other ways to access the vehicles and payment options, such as rechargeable cards and telephone calls to unlock e-scooters (City of Chicago, 2020). These, among others, are some important measures that need to be taken when planning micromobility and shared micromobility, in order to promote a more equitable usage around the city.

Micromobility solutions can also act in favour of a more equitable placement of micro-vehicles in cities, as special programs and policies can be created to allow a better distribution of shared bicycles and e-scooters around the city (Dias et al., 2021). These measures can reduce gender gaps in transport use, as women can feel safer on micro-vehicles, once they are smaller in comparison to other transport modes (International Transport Forum - ITF, 2020). Also, women are more distance-sensitive and are less likely to bike long distances, and both e-bikes and e-scooters enable everyone to travel greater distances easily (CB Insights, 2019).

Furthermore, micromobility offers economic benefits at both macro and personal levels, as it can be a price-efficient alternative to the car in denser areas, as well as a contribution to the economic vibrancy of the city centres and downtown commercial districts (Gardner & Gaegauf, 2014) because it allows people to have more contact to their surround.

Figure 2 shows a collection of impacts that can be achieved with shared micromobility usage in cities in its three main dimensions, such as environmental, social, and economic.

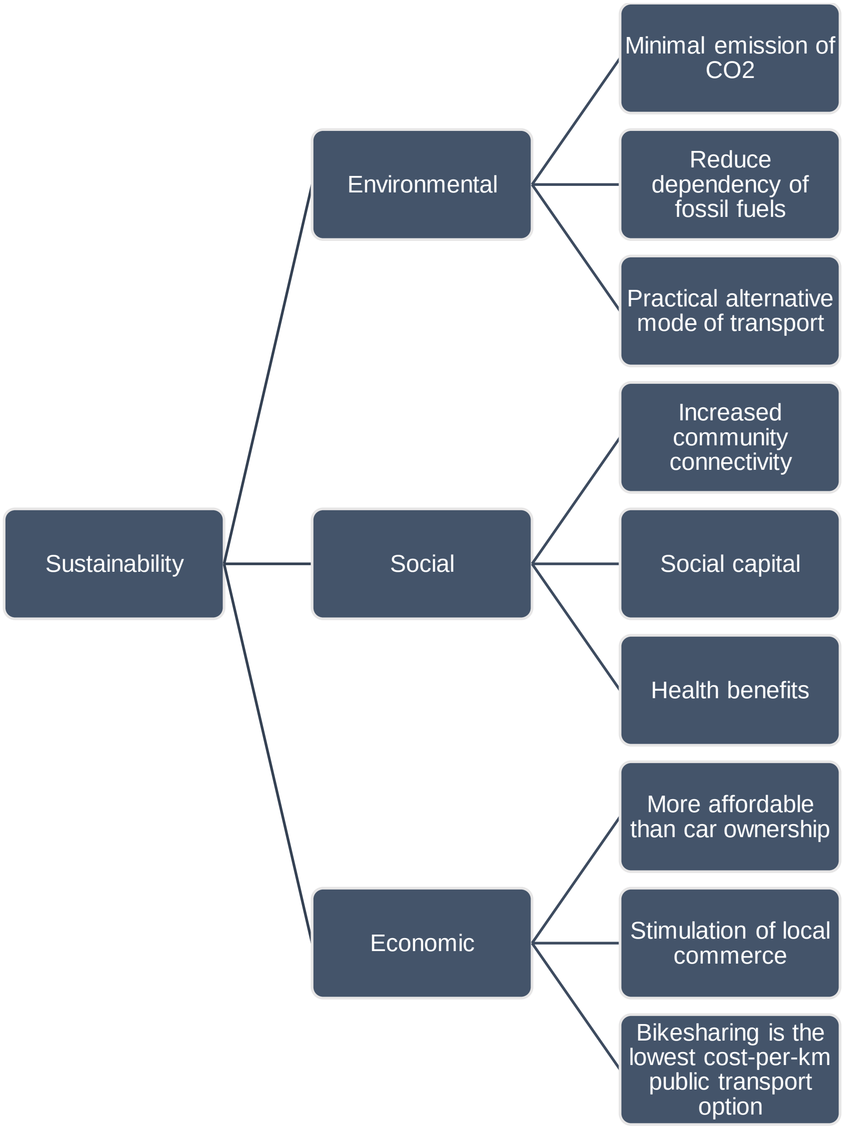

Figure 2: Environmental, social, and economic impacts of micromobility in sustainability
Source: (Gardner & Gaegauf, 2014)

As it can be seen in Figure 2, the employment of shared micromobility options in cities can lead to great impacts on sustainable urban mobility. It starts with a modal shift from cars, which reduces traffic and air pollutions, to the reduction of health problems and the increase of community connectivity. Also, these transport modes are more affordable than car ownership and can be implemented in cities with a lower cost.

3. METHODOLOGY

This research systematically analyses the scientific literature available regarding micromobility and how their impact could be measured in terms of sustainability when considering the environmental, social, and economic impacts generated by its usage. Thus, the literature available about the subject is composed of scientific journal publications, company reports, and studies, as well as manuals edited by urban mobility experts. The procedure to collect the literature was composed of four different phases (Dias et al., 2021), which started with a comprehensive gathering of literature using relevant databases, such as Scopus, Google Scholar, and Clarivate Analytics. In addition, Google was also used as a source of documents from research companies and reliable transportation entities.

Phase 2 was composed by the application of general keywords for research, such as “Micromobility”, “Sustainable Micromobility”, “Micromobility and Environment”, “Social impact of Micromobility”, and “Economics of Micromobility”. The articles selected were published in journals indexed in Clarivate Analytics and/or Scopus, once these databases include works that go under more rigorous revision processes. In addition, reports and documents from established entities were selected.

Further, phase 3 was composed of the snowballing technique to incorporate additional literature that was identified in the citations made in each publication previously incorporated (Van Wee & Banister, 2016). After these 3 phases, 55 documents were obtained. To conclude the research process, phase 4 was performed, which represented a narrowing of the relevant literature found in phase 3, which resulted in a total of more than 40 documents. Yet, these documents were studied and analysed in depth especially regarding the matter of how sustainability can be measured when using micromobility and shared micromobility in the three aspects of sustainability, which are environmental, social, and economic. A scheme of the steps used in the methodology is presented in Figure 3.

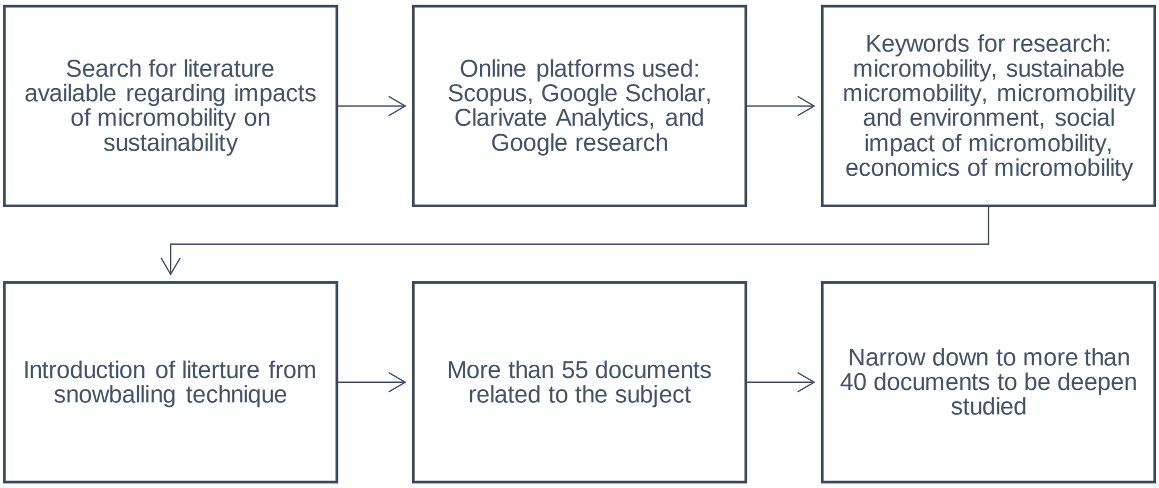

Figure 3: Steps used in the methodology

This information was retrieved in order to explain how micromobility can contribute to sustainable urban mobility, and how the sustainable impacts can be measured in different contexts. Once this can help policymakers and general stakeholders to better understand this mobility trend and to better apply it in cities to promote sustainable urban mobility.

4. SUSTAINABILITY MEASUREMENT IN MICROMOBILITY

This section of the paper investigates the main methodologies used to measure and analyse the sustainability of micromobility modes in cities. Firstly, it is going to be presented how environmental impacts of micromobility can be measures, followed by social impacts and economic impacts.

4.2 Measurement of environmental impacts

The most common standardized method to analyse the environmental impacts of a product through its entire life cycle is the Life Cycle Assessment (LCA) (Luo et al., 2019). And it is also the most used method to assess the environmental performance of a product-service system, which can be configurated as a shared micromobility system (Moreau et al., 2020). According to Moreau et al. (2020), The LCA is a quantitative environmental impact assessment method that permits the calculation of the impacts of a product or a service through all life cycle phases on the environment. This includes resource extraction, raw material processing, product assembly, transport, packaging, use, maintenance, waste treatment, and disposal (Finnveden et al., 2009; Rebitzer et al., 2004). Table 1 shows the studies used to investigate how LCA is used to estimate the environmental impacts of micromobility.

Table 1: Environmental sustainability in micromobility

Reference	Type of micromobility	Parameter analysed
Chang et al., 2016	Scooters	Carbon footprint between hydrogen scooters and e-scooters
Luo et al., 2019	Bicycle	GHG emission factor between dockless and station-based bike-sharing
Hollingsworth et al., 2019	E-scooters	Global warming potential of shared dockless e-scooters
Moreau et al., 2020	E-scooters	Life cycle carbon footprint of e-scooters
D'Almeida et al., 2021	Bicycles	CO2 emissions by shared bicycles

The work performed by Chang et al. (2016) is set on defining the total greenhouse emission from direct and indirect processes caused by scooters. For this, all service life of this micro-vehicle was analysed, such as the obtainment of raw materials, the service flow, and the output during service flow, which is translated into the manufacturing of the pieces (e.g., tires, bulbs, gear oil, engine oil, lead-acid batteries), the environmental impact during service (e.g., cruising, use of gasoline or electricity), and the impacts after the scooter's usage (e.g., waste tires, waste bulbs, waste engine oil, waste lead-acid batteries).

For this study, Chang et al. (2016) calculated the carbon footprint (kg CO2eq/pkm) per functional unit using life cycle carbon emissions divided by the functional units. The scooter service carbon footprint is thus calculated by the total carbon emissions divided by the mileage and scooter load factor, which then shows the emissions for a scooter carrying one person and traveling one kilometre. After the study, it was concluded that the methanol steam reforming scooter has the lowest carbon footprint, while the internal combustion engine scooter has the highest carbon footprint.

The work performed by Lou et al. (2019) is set on comparing the station-based and dockless bicycle sharing systems from life cycle perspectives. If compared to other studies, the research differs because they analyse the net environmental impacts of bike-sharing programs holistically (in terms of greenhouse gas emissions and the total normalized environmental impacts), as well as comparing both ways of providing the service, namely in a dockless or station-based form.

To evaluate the environmental impacts through LCA, this research analysed the greenhouse gas emissions from two systems (station-based and dockless). Additionally, it was investigated the total normalized environmental impacts to attain the overall impact, considering all the impact categories. Due to the uncertainty of the input data, the researchers conducted a sensitivity analysis to evaluate how different systems setup and operation would impact greenhouse gas emissions and total normalized environmental impacts values. Also, to better evaluate the two systems, the break-even point was analysed to identify key parameter values that can make two systems have the same environmental impacts. In the end, dockless bike-sharing systems demonstrated a higher emission factor than station-based systems, mainly due to more intensive rebalancing demands (Luo et al., 2019).

To assess if e-scooters are a green alternative to urban mobility, Hollingsworth et al. (2019) performed a Monte Carlo analysis with assumed distributions for relevant parameters to determine the overall distribution of life cycle impacts. To perform the analysis the following inputs were considered: material manufacturing for e-scooters (kgCO2eq/scooter), collections and distribution emissions (kgCO2eq/scooter), transportation to the US (kgCO2eq/scooter), scooter use and maintenance (collections and distributions, end of day battery charge, scooter lifetime, and time to begin charging). Also, some static variables were used, such as scooter distance potential (miles), energy per full charge (kWh), time to fully charge (h), and power required to charge (kW).

As a result, it was found that the global warming impacts associated with the use of shared e-scooters are dominated by materials, manufacturing, and automotive use for e-scooter collecting and charging. Increasing scooter lifetimes, reducing collection and distribution distance, using more efficient vehicles, and less frequent charging strategies can reduce adverse environmental impacts significantly (Hollingsworth et al., 2019)

To compare the environmental impact caused by shared and personal e-scooters, Moreau et al. (2020) used the LCA in two different forms. To estimate the environmental impacts of shared e-scooters the researchers used inputs that include displacement to be charged, and distributions, while to assess the personal e-scooter impact, these variables were not considered. After the analysis, it was found that shared dockless e-scooters cause more environmental hazards than personal micro-vehicle.

On the other hand, to estimate the environmental impacts of bike-sharing schemes' emissions, D’Almeida et al. (2021) used LCA with inputs such as emissions from production, emission from use, emission from operations, and end of life disposal. After the analysis, it was found that, in the case study of Edinburgh, the bike-sharing systems only reduce CO2 emissions by 0.5%, which is small but represents a move into a more environmental-friendly mode of transport.

4.3 Measurement of social impacts

To measure the main social impacts caused by the usage of micromobility in cities, two different methodologies are usually used, namely geospatial analysis to evaluate the spatial coverage of the services and availability of micromobility to the populations, including vulnerable populations and the ones that do not have proper access to other modes of transport, such as private and shared cars, and public transport.

The other methodology used is the application of surveys to identify the characteristics of the users of different micromobility services, such as shared bicycles and shared e-scooters. This methodology is usually used to determine the main purposes of trips, socio-demographic and intention of service, and characteristics of trips according to the users' perspective. Table 2 shows studies used to investigate the social impacts of micromobility usage in cities according to geospatial analysis and surveys.

Table 2: Social sustainability in micromobility

Reference	Type of micromobility	Parameter analysed
Clewlow et al., 2018	Bicycles and E-scooters	Measurement of equitable access to micromobility
Caspi et al., 2020	E-scooters	Trip patterns of e-scooters
Lee et al., 2021	E-scooters	Heterogeneity in people's intention to use e-scooters
Almannaa et al., 2021	E-scooters	Feasibility of launching e-scooter systems
Duran-Rodas et al., 2021	Bicycles	Planning bike-sharing through demand/equity method

The research performed by Clewlow et al (2018) is based on the primary equity analysis methods, such as measuring the equitable availability of vehicles, measuring the equitable utilization of vehicles, and evaluating compliance with designated mobility zones or hubs, as well as determining the demographic profile of the people who are using micromobility services.

The measurement of the equitable availability of vehicles is made with the provision of GPS or location-based data of the vehicle locations (e.g., bicycles, e-scooters, or cars). This metric analyses and measures the vehicles available by specific zones, including for example districts, specific Census tracts, or other geographies used by the cities to designate disadvantaged populations. To assess and define equitable vehicle utilization and the use of micro-vehicles by people with different demographic attributes, the location of trip starts, or ends is examined to determine the distribution of vehicles and utilization by geography. To determine the geographic profile of users, a survey is applied to collect information.

The study of Caspi et al. (2020) focuses on exploring the usage of shared e-scooter usage in the city of Austin, TX in the United States. To assess the results, the researchers based their work on trip records of all the shared e-scooter operations in Austin, including trip start and end locations. The trip patterns and spatial regression techniques were used to examine how the built environment, land use, and demographics affect e-scooter trip generations. The results showed that the use o shared e-scoters are exclusively made in the city centre of Austin, and around the downtown area and the University of Texas, which shows a lack of fair distribution of the trips and e-scooter locations in the city. Although, during the week, the lower the income in the area, the more departures and arrivals take place during the morning. This can represent a higher usage of low-income people as a displacement option to go to work and school.

To assess the factors affecting heterogeneity in willingness to use shared e-scooters, Lee et al. (2021) performed an online survey aiming to analyse how people's intentions to use shared e-scooters change according to the trip situations (e.g., trip time, trip purpose, and trip type). The results show that people with relatively low willingness to use shared e-scooters represent a large market share, as they have relatively low incomes and prefer shared e-scooters for first-and-last mile trips in university districts. Although, this information shows that the answers from the survey came from a very specific public, which is university students, and do not represent the whole picture of the shared micromobility usage in cities.

In order to explore the feasibility of launching a shared e-scooter system in a city, Almannaa et al. (2021) performed a survey to collect socioeconomic and demographic information, as well as mobility and e-scooter perception. As a result, respondents showed a willingness to use shared e-scooters in open entertainment areas, shopping centres and malls, building complexes, residential areas. A few female respondents said they would use the service, while more than half of male respondents would use the service. On the other hand, almost forty percent of the respondent with the lowest income range would rely on the service for their daily trips. In short, the results show that depending on, for this case, the policies and the arrangement of the e-scooter sharing service should the made in order to encourage women to ride, and made e-scooters available in low-income areas, so people living there could have the opportunity to use the service.

To help better plan bike-sharing systems in cities, Duran-Rodas et al. (2021) used the demand and/or equity method for planning the allocation of bike-sharing system stations and their services based on spatial fairness, which includes spatial equity, efficiency, and equality. To do so, three main types of spatial data need to be collected, such as i) historical bike-sharing trips, including the time and location of rentals' origins and destinations, station locations, and service area boundaries; ii) built environment data (e.g., transport infrastructure); iii) social environment (e.g., transport's mode choice, milieu, sociodemographic).

To find the best fit for bike-sharing allocation, the methodology proposed can be described in seven different staps, which are: i) selection of a study area, and dividing it into zones of analysis; ii) collecting data from the built and social environment, generating features and aggregating them into categories; iii) estimating deprivation in each analysis zone or an index showing where underprivileged people live; iv) estimating potential ridership in each analysis zone or other variables related to “productivity” (e.g., systems’ earnings); v) ranking zones of analysis in terms of equity and efficiency; vi) creating scenarios based on the number of (virtual) stations according to the available budget; vii) comparing scenarios in terms of density and coverage.

4.4 Measurement of economic impact

As there is still a lack of knowledge about the economic impacts of shared e-scooter systems in urban sustainable mobility, this section focuses on the economic impacts of bike-sharing systems, as they represent micromobility options in cities. Table 3 shows studies that measured the economic impacts of the usage of micromobility in cities.

Table 3: Economic sustainability in micromobility

Reference	Type of micromobility	Parameter analysed
Bullock et al., 2017	Bicycles	The economic contribution of bike-sharing to cities
Qiu & He, 2018	Bicycles	Economy related externalities of bike-sharing
Martinez et al., 2019	Bicycles	Economic impacts of bike-sharing
Gao et al., 2021	Bicycles	Quantification of economic bike-sharing benefits

In order to assess the economic benefits of bike-sharing systems, Bullock et al (2017) performed a survey around bike-sharing stations in commercial shopping districts, high levels of commuters, heavily trafficked areas, and areas containing more recent stations. The survey was composed of questions on users’ characteristics (e.g., purpose, time, duration, journey stages, origin, and destination), previous journeys (mode, duration), reasons for using bike-sharing and perceived health. The results show that levels of modal shift from cars, contributions to health from more physical activities, reduced journey time make a considerable contribution to urban economics.

To estimate the positive economic benefits of bicycle-sharing programs, Qiu & He (2018) estimated the change in commute time when office workers choose bike-sharing instead of walking from home to bus stops or from station to the workplace, which leads to the estimate of the economic effect due to the change in the duration of the trips. After, the estimate of the kilometres travelled provided by existing bike-sharing services, and the change in energy consumption it generates instead of using fossil-fuelled vehicles, in the end, the health effects are calculated in terms of expenditures in hospitals related. The results show that bike-sharing services help users and the government to save money due to changes in trips characteristics and health expenses, respectively.

The measurement of economic benefits of bike-sharing programs in European country's economy was performed by Martínez et al. (2019). The first part of the assessment is made by applying Leontief input-output matrices that capture the economic interdependence between the different economic sectors, which makes it possible to assess the economic activity generated by each bike-sharing project for the whole country's economy. To measure the health effects, the analysis relies on the WHO tool HEAT to compute the impact of bike-sharing use on the number of premature deaths. Thus, both calculations, once translated into monetary terms, are aggregated into a single indicator, expressed in euros.

On the other hand, Gao et al. (2021) made a quantitative assessment of the economic benefits of bike-sharing programs for users, in which, an innovative trip-level inference approach is used, as well as routing online navigation travel choice modelling. The results show that economic benefits from bike-sharing in different urban contexts vary substantially and have significant associations with the built environment. The built environment factors including populations density, accessibility to metro and bus stations, land use entropy, commercial land use ratio, parks, and square land use ratio, and road density, are found to have significant linkages with the economic benefits of bike-sharing systems.

5. DISCUSSION

Micromobility was introduced in cities as a means to thrive sustainable urban mobility. The deployment of infrastructure and technological support for bicycles, shared bicycles, e-scooter, and shared e-scooters was meant to influence dwellers to switch from private fossil-fuelled cars to cleaner options that could also work to promote more inclusion and savings for users.

Although, cities need to be planned to receive these micro vehicles in order to allow them to provide the best service. It is crucial that specific planning, testing (e.g., pilot programs), and space are created to accommodate micromobility in a way that it can work as a first-and-last mile option connected with public transport, as well as an alternative for short-distance trips that are currently made by cars.

To access if micromobility is fulfilling its goal of providing a sustainable mobility option for users, many methodologies are used. To study the environmental impacts, the Life Cycle Assessment (LCA) is the most common one. This methodology uses the carbon footprint of all parts of the life cycle of services and objects to measure their environmental impact. In the case of micromobility, it starts with the carbon footprint of the materials used to assemble the vehicles, going through the pieces, the operation of the vehicle, and the impacts after it is not used, that is, the pollution caused by the waste produced by the parts of the micro vehicle.

There are many ways to compare the carbon footprint of micro vehicles and micromobility in general in the environment. The study performed by Chang et al. (2016), for example, compared the LCA between fossil-fuelled and hydrogen scooters to check which one is the most polluting. As a result, methanol steam reforming scooters have the lowest carbon footprint. While the comparison between station-based and dockless bike-sharing programs showed that dockless services cause more harm to the environment than the station-based (Luo et al., 2019). More recently, with the introduction of e-scooter sharing systems in the cities, it was needed to evaluate its environmental impacts as well, for this Hollingsworth et al. (2019) Moreau et al. (2020) performed two LCA to measure the impacts of the introduction of these vehicles in cities, and the comparison between shared and personal e-scooters. The results show that shared e-scooters trips themselves do not have a high effect on the environment, nonetheless, the manufacturing, transport of pieces, and vehicles have a great negative influence on the environment. Also, shared e-scooters, without the proper planning in cities, have more negative impacts on the environment than personal e-scooters. The main results found by each research are shown in Table 4.

Table 4: Main results from LCA in micromobility

Reference	Type of micromobility	Results
Chang et al., 2016	Scooters	Hydrogen scooters have the lowest carbon footprint if compared to internal combustion engine scooters.
Luo et al., 2019	Bicycle	Dockless bike-sharing systems have higher GHG emission factors than station-based systems, due to rebalancing demands.
Hollingsworth et al., 2019	E-scooters	The carbon footprint associated with materials, manufacturing, and automotive use for e-scooter collection and charging.
Moreau et al., 2020	E-scooters	Need of increased lifespan of e-scooters to reduce their life cycle carbon footprint
D’Almeida et al., 2021	Bicycles	Bikesharing scheme reduces CO2 emissions but needs to be planned in order to substitute car trips

When the social impacts need to be studies and measure, the most common tool used is the spatial analysis to identify how the vehicles are distributed and if the special availability is under the principle of offering transport for all, including more distant and unprivileged areas. The social impacts studies should be made even before the employment of any micromobility services in cities, in order to, since the beginning, promote a more equitable usage of this mode of transport. These studies should be part of any project to provide micromobility that can be used in areas where public transport does not reach.

Also, another important tool to assess the social impacts of micromobility in cities in the survey. This mechanism is highly recommended to be used when it is needed to evaluate people's willingness to use micromobility and to identify their socio-demographic characteristics, as well as the best options to provide a more accessible mode of transport for all (e.g., price range, special low-fare programs, options of payment). The main results from each research can be found in Table 5.

Table 5: Main results from social impacts research

Reference	Type of micromobility	Results
Clewlow et al., 2018	Bicycles and E-scooters	Micromobility can help cities achieve transport equity if cities evaluate the availability of the services and develop policies to incentivize equitable placement of micro vehicles, as well as equitable usage.
Caspi et al., 2020	E-scooters	E-scooters are more used for recreational purposes in the central area of the city (Austin, TX), representing a lack o equity in planning the service.
Lee et al., 2021	E-scooters	Low-income people have a low willingness to use shared e-scooters if there is no policy for fare reduction in cities, even if it is available in their residential area.
Almannaa et al., 2021	E-scooters	Gender, age play an important role in the willingness to use e-scooters, which needs to be considered when planning the system before implementation.
Duran-Rodas et al., 2021	Bicycles	Bike-sharing schemes can be planned to allocate stations according to spatial equity and efficiency.

After the environmental impacts are measured, along with the social impacts, it is also important to assess the economic effect that can be generated by the usage of micromobility. As e-scooters are still “new” in cities, there is a lack of studies about these micro vehicles, on the other hand, bicycles were tested to check how they can contribute to monetary savings in urban mobility.

To estimate the economic benefits of micromobility, surveys can be used to check users' usability of the service, as well as their socio-demographic characteristics. But the most common economic assessment made is the conversion of health benefits, the economic activity generated by the use of micromobility, to monetary units. This way, a specific value can be attributed to the benefits of shifting from private cars to bicycles or e-scooters in cities. The main result from each research is presented in Table 6.

Table 6: Main results from economic impacts research

Reference	Type of micromobility	Results
Bullock et al., 2017	Bicycles	Bikesharing contributes to journey time savings and improved city connectivity (connecting public transport terminals to workplaces), which makes a considerable contribution to the urban economy.
Qiu & He, 2018	Bicycles	Usage of bike-sharing help residents to save time, and increases connectivity to other modes, which contributes to an increase in the total GDP of a city.
Martinez et al., 2019	Bicycles	The aggregate value of the socioeconomic effects (impact on the economy and health benefits) for each euro invested in bike-sharing programs is estimated to be between €1.37 and €1.72
Gao et al., 2021	Bicycles	Economic benefits from bike-sharing systems vary substantially with the built environment, but saved travel time, cost, and the economic benefits from these systems represent economic benefits for cities.

In short, cities must make efforts to measure the impacts caused by the introduction of micromobility options with the methodologies already available that were presented in this paper. Only this can assure that the best micromobility option is applied in the city to help achieve the sustainability goals and sustainable urban mobility.

6. CONCLUSION

Micromobility is a very important tool that can complement the transport system in cities all over the world. They can be used as a first-and-last mile option to complement public transport, as well as the replacement of short car trips. Although, the implementation of micromobility needs to be very well planned and studied in cities, in order to make the most positive impacts out of them, such as reduction in time-travel and air pollution, provision of a mobility option that can advocate for better inclusion of all types of users, and that generates economic benefits for users and the city.

To measure all the benefits for urban sustainability from micromobility, many methodologies can be used, although, this research work focused on the most used ones. For environmental impacts, the LCA can be used, followed by the social impacts that can be assessed by geospatial analysis and surveys, and finally the economic impacts that can be measured by the conversion of the benefits from micromobility into a monetary unit.

All these tools need to be used by city planners to better formulate the micromobility systems that can be integrated into urban areas. It is very important that before the implementation some impacts have been assessed in order to better understand which micromobility option is the best one to be implemented, as well as the best way to offer the service to the population, so sustainability goals can be achieved.

Nonetheless, it is also important to understand that from the methodologies presented here, other questions can come to mind, such as the understanding of e-scooters utilization more deeply to measure their real environmental benefits for the society, as well as the modal share that needs to be achieved in cities in order to provide an optimal life cycle carbon footprint for micromobility modes, so cities can rely on them to have sustainable mobility.

In short, urban sustainable mobility can be achieved by the implementation of micromobility options, such as bicycles, bike-sharing programs, and shared e-scooters systems. But the planning is very important before the deployment of the systems, as well as the assessment of the impacts they generate in urban mobility in the three pillars of sustainability, which are environmental, social, and economic.

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