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RESEARCH ARTICLE

Motorized three-wheelers and their potential for just mobility in Caribbean urban areas

Mariajosé Nieto-Combariza[1], Andrea San Gil[2], Adriana Quesada[2], Dayana Agudelo[3], Julian Arellana[3] and Daniel Oviedo[1]

[1]University College London, London, UK
[2]Agile City Partners and Global Partnership for Informal Transportation, San José, Costa Rica
[3]Universidad del Norte, Barranquilla, Colombia
Corresponding author: Daniel Oviedo; Email: daniel.oviedo@ucl.ac.uk

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Abstract

This paper investigates the role of motorized three-wheelers (MTW) in urban mobility within popular transport, a demand-responsive and unscheduled mode of transportation provided by self-organized small operators frequently operating in grey areas of regulation. Although popular transport is the primary mobility option for millions worldwide, knowledge about its users, operation, and environmental and social impacts remains scarce. This paper sheds light on some of the features and impacts of popular MTW, focusing on two case studies in the Caribbean with different scales and urban trajectories: Puerto Viejo, Costa Rica, and Soledad in Colombia. We explored the relationship between MTW and fragmentation–(in)accessibility–exclusion in these cities, drawing on a framework connecting these concepts in the Latin American and Caribbean context. Using primary data from qualitative and quantitative methods, the paper examines the distribution of inhibitors or enablers of accessibility within the context of unequal, splintered, and fragmented transport and communication infrastructures. Additionally, the environmental impact of MTW in terms of CO_2 and PM2.5 emissions is assessed using field data from low-cost sensors. The paper argues that planning for just urban mobility necessitates considering the ecological consequences of various transportation modes and their social consequences and potential for participation and inclusion. The applied methodology introduces low-cost, replicable, and scalable data production and analysis techniques, contributing to future research on sustainable and just mobility in resource-limited urban areas.

Policy Significance Statement

This study explores the role of motorized three-wheelers (MTW) in urban mobility, addressing previously unmet needs in Puerto Viejo, Costa Rica, and Soledad in Colombia. MTWs contribute to increased accessibility, particularly for livelihoods, recreation, and care activities, and adapt to changing geographies of transport supply. However, their impact on education accessibility is less clear. The flexibility of MTWs, combined with their ability to provide transport at different scales of operation and spatial coverage, allows them to bridge gaps in transport networks. The study also highlights the importance of addressing safety concerns, affordability, and environmental impacts of MTWs to ensure sustainable and just urban mobility for all.

1. Introduction

How do people move when public transport is inaccessible, infrequent, or unreliable? "Popular transport", also called informal, artisanal, or paratransit, among other terms, are transport services that are usually demand-responsive, unscheduled, and flexible, provided by self-organized small operators, in small- to medium-sized motorized or nonmotorized vehicles. These services generally operate in grey areas of regulatory frameworks or government planning and are privately developed without an official endorsement for market entrance or for the practices of operation and organization. These transport services are the only livelihood and mobility option for millions of people around the world, being particularly important in peripheral and disadvantaged areas (Behrens et al., 2021; Tun et al., 2021).

Despite the ubiquity of popular transport, knowledge and information about its users, operation and the role it plays in environmental and social issues is scarce. In most cities where these forms of mobility operate their impact on accessibility, wellbeing, sustainability or equity remains unknown (Behrens et al., 2021). Robust evidence about the potential and limitations of these transport modes is paramour for urban mobility governance to meet the aims of an effective, efficient, and just transport system. So far, studies about public transport configuration and characteristics, user behavior and perceptions, and how these shape more socially just forms of urban mobility have been predominantly focused on high-capacity passenger transport vehicles (i.e., buses, vans, jeepneys). More recently, the rapid growth of motorcycle mobility in Latin America (Rodríguez et al., 2015), African (Diaz Olvera et al., 2019), and Asian cities (Jones et al., 2013) has shifted the attention of transport scholars and transport institutions to two-wheeled vehicles. Nonmotorized transport has also received increased attention connected with concerns about carbon, energy, and health (Schwanen, 2016). MTW, by contrast, have been largely left out of these discussions. Much knowledge about these vehicles as a form of public transport is highly concentrated in cases in Asia with only one known study about three-wheeled vehicles in Latin America, albeit in a rural context.

This paper seeks to address this knowledge gap about popular transport with two case studies of the role of MTW in urban mobility in two urban areas in the Caribbean. The comparative study generates evidence about the relation of a rapidly growing form of mobility with the process of fragmentation-(in) accessibility-exclusion in cities with different scales and urban trajectories: Puerto Viejo in Costa Rica and Soledad in Colombia. Building specifically on Oviedo's

2. Why Three-wheelers?

Individual and collective popular transport services provided through three-wheeled motorized vehicles have claimed a space in the urban mobility landscape of many cities. Up to the last decade, according to Mani et al. (2012), 75% of the world's MTW were in India, where they emerged in the 1950s as a flexible demand-responsive public transport mode with the destination being defined by the passenger. More recently and known by different names than the original auto-rickshaw, MTWs have become part of urban mobility of cities in Europe (Piaggio Ape), South and East Asia (Tuktuk, Bajaj, tricycles), Africa (keke-marwa, raksha, tuktuk) and Latin America (cocotaxis, motocarros, toritos). In Central America, a study of popular transportation found that MTW mobility was present in five of the six countries analyzed (Morales-Miranda et al., 2021). The authors estimate 23,900 vehicles in El Salvador, Nicaragua, Costa Rica, Guatemala, Panamá, and Honduras based on secondary data. In Colombia, the widespread demand and presence of these vehicles in all regions of the country gave rise to national and local government regulations targeting specifically MTW vehicles for public transport, and by 2020, there was an estimated fleet of 24,000 vehicles (Nieto-Combariza, forthcoming). Similarly to other small-scale services, particularly those operating in the grey areas of current regulations, the literature on these services is limited. Furthermore, with MTW being a relatively recent phenomenon in Latin America and the Caribean, there are no published studies analyzing MTW potential and risks in relation to equity, sustainability, or road safety. The importance of addressing this gap is particularly evident in urban areas of the region where the

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use of these vehicles is increasing. This significance arises from the need to understand the effects of these vehicles from both an equity and sustainability perspective. This includes their impact on road accidents and deaths, especially in places like Puerto Viejo, where official information is lacking and considering that where there are official reports like in Soledad there is evidence to argue that MTWs are safer than other small-scale vehicles such as cars and motorcycles.

The existing knowledge, although scarce and highly concentrated on South and East Asian urban areas, shows the potential of these vehicles as a form of public transport that advances sustainable mobility goals (Garg et al., 2010; Reynolds et al., 2011; Mani et al., 2012) and contributes to more equitable urban spaces (Harding et al., 2016). In India, Garg et al. (2010) and Mani et al. (2012) identify the potential of auto-rickshaws for sustainable mobility in three characteristics: being an affordable first and last-mile connection, becoming an alternative to ownership of private motor vehicles, and because these vehicles have a low rate of pedestrian fatality (Mohan and Roy, 2003), linked to their speed and weight. The fatalities of occupants are a concern suggested to be addressed through vehicle design improvements introduced through motor vehicle safety regulations. The authors also indicate that the performance of two-stroke engine vehicles needs to be improved to reduce the emission of PM2.5, suggesting moving to four-stroke engines and fuel-related regulations to avoid higher NO_x emissions from this type of engine. The studies in India also suggest auto-rickshaw-specific infrastructure and driver training to improve road safety and operational problems. Garg et al. (2010) highlight the importance of improving the public image of these services and the conditions of social protection for drivers.

Regarding social sustainability, Guillen and Ishida's (2004) study in the Philippines stresses the good relationship between residential owners' and drivers' associations based on the presence of vehicles in most residential areas. Harding et al. (2016) show the contrast between the perception of the public media and policymakers and the actual contribution to congestion, air pollution, and safety of these vehicles. The authors' analysis underscores the economic precarity of drivers and how their challenging day-to-day reality could be related to some of their negatively perceived actions, such as not going by the meter. The authors' assessment of policy recommendations concludes with suggestions for actions such as permit systems, access to credit, regular fare revision, and the phasing out of older, more polluting vehicles like two-stroke engines.

Also in the Philippines, a case study in Siquijor Province, Rahman (2012) shows that MTW serves 15% of the trips, mostly short rides (within 0.5 km) done by students (it is their main mode of transport) without a significant link to income. In a rural context in Colombia, Saldarriaga Castrillón (2011) finds that travel time and age are key variables in using MTW for public transport. Also, in a rural context, Starkey et al. (2021) highlight the fundamental role of MTW (in this case, six-seaters with routes) in three districts of Punjab Province, accounting for more than half the journeys done by women. The reason is that motorcycles driven by men are unavailable for women's multipurpose trips during the day, and taxis are more costly, leaving MTW as the only low-cost alternative. Furthermore, the authors find that women are more willing to pay for less crowded, safer vehicles than men, which in this case are MTW. Gadepalli et al. (2020) identify age, gender, and income as social characteristics with a statistically significant relation to using auto-rickshaws. MTWs are specifically preferred by women, the young (school students being the single largest group of users, twice larger than the next group), and daily wage employees (classified as working in the informal sector). Like in the Philippines' study, income does not seem to influence the preference to use buses or MTW. In a study of school transport in Kandy, Sri Lanka, MTW were used for walking and medium distances with an average of 5.5 km and had the shortest average distance of the private vehicles used for the medium distance bracket. Public transport modes covered longer distances. Similarly, to Gadepalli et al. (2020), gender is related to the use of MTW with female students preferring to use these forms of mobility instead of public buses, walking, and private vehicles. The authors associate their preference with greater safety and security as documented in other studies in South Asia (Dias et al., 2022). In sum, the available information points to the functionality of these vehicles in the mobility of disadvantaged and socially excluded inhabitants and the livelihood of vulnerable segments of the population.

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3. Conceptual Framework: Just Urban Mobility and Three-wheelers

Questions of urban mobility justice entail understanding how (for whom, when, and in what ways) a form of mobility, in this case, MTW, relates to uneven conditions of access to places and to valued forms of mobility. Transport and mobility research has considered at length the interconnections of the ability and conditions to move to different dimensions of injustice. Transport systems, modes, policies, and regulations have been studied analyzing the distribution of their cost and benefits and the causes and consequences of said distribution (see Henderson, 2004; Hasan and Dávila, 2018; Hine and Grieco, 2003). The uneven distribution of access to transport and mobility (including the quality of said transport and mobility) has been linked to and deemed to be a form of poverty and social exclusion (Oviedo, 2021). Social exclusion, transport disadvantage, and social capital can be understood as intertwined processes: in any locality, for any individual, community, and/or social group, there are likely to be several overlaps and pathways through which these processes affect, and are affected by, each other (Neutens, 2015; Schwanen et al., 2015; Lucas et al., 2016; Rowangould et al., 2016).

In this study, the relation between social exclusion and poverty to transport disadvantage and mobility is understood through accessibility. Building specifically on Oviedo's (2021) connection of accessibility to social and spatial inequality and social exclusion, the potential of MTW is analyzed in light of the effect of this form of mobility in the distribution of inhibitors or enablers of accessibility. The acknowledgment that access is a relative concept that varies according to the level of opportunity afforded makes assessments of access meaningful only by comparing access in one zone to access in another (Fransen et al., 2015; Brussel et al., 2019; Han et al., 2015; Kaza, 2015; Mclafferty, 2015; Talen, 2015; Wang and Chen, 2015; van Wee, 2016). Accordingly, the analysis of accessibility in different areas in cities in Latin America is contextualized in a macro dimension of unequal, splintered, and fragmented distribution of material infrastructures for transport and communication (Oviedo and Dávila, 2019). The planning and provision of transport networks moderate or enhance accessibility, aggravating or reducing social inequality (Manderscheid and Bergman, 2008; Manderscheid, 2009).

The potential of MTWs for just mobility in urban areas is assessed in terms of their contribution to breaking or mitigating the mutually reinforcing process of fragmentations stemming from splintered urbanism that leads to inaccessibility and, in turn, exclusion (Oviedo, 2021) (see Figure 1). However, considering the study's timeframe and the macro-long-term dimension of urban configurations, the

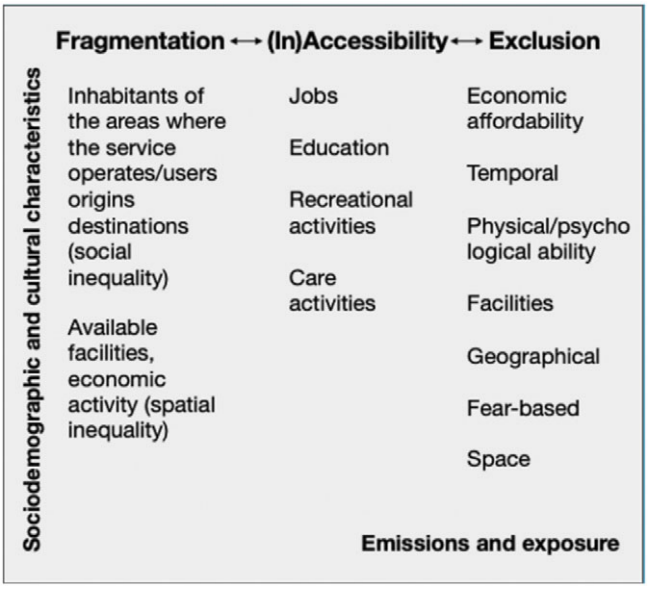

Figure 1. *Disrupting the reinforcing process of fragmentation-inaccessibility-exclusion.*

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analysis of MTWs' role in disrupting fragmentation is limited to describing its relationship to existing infrastructures in the two case studies. Therefore, the disruption of fragmentation-inaccessibility-social exclusion is evaluated at two levels: (i) the access to jobs, education, recreation, and care activities that this form of mobility enables and (ii) the characteristics of mobility in MTW that facilitate overcoming instances of social exclusion. The typification of social exclusion in seven categories: economic affordability, physical/psychological ability, geographical, temporal, facilities, fear-based, and space (control) follows Church et al.'s (2000) framework building on Oviedo's (2021) adaptation to analyze the links of accessibility, social and spatial inequality, and social exclusion in Latin American cities.

Furthermore, acknowledging differential abilities and values requires an intersectional perspective focusing on the subjective experience of these mobility opportunities (Pereira et al., 2017). Such a lens is attentive to the accessibility of the otherwise marginalized and excluded. Research has shown that low-income communities and ethnic minorities are often exposed to greater harm and enjoy fewer benefits from transportation systems than the general population (Neutens, 2015; Schwanen et al., 2015; Lucas et al., 2016; Rowangould et al., 2016). In this research, we used five sociodemographic and cultural characteristics to analyze the relation of gender, ethnicity/race, age, class (using education and income as proxies), and disabilities.

Finally, the potential for just mobility concerning the MTWs' sustainability is understood through the distribution of environmental space. As an analogy of Guzman L et al.'s (2021) analysis of transport justice through the distribution of road space between vehicles, this study identifies the environmental space occupied by mobility in MTW in terms of CO2 and PM2.5 emissions. The contribution of MTW to air pollution and greenhouse gas emissions is a proxy for the share of environmental space used by these services. The concept of environmental space was developed by Siebert (1983) to represent the limited nature of Earth's ecosystems' capacity to endure pressure and keep supporting life. Such support can be stocks of resources and sinks (Folmer et al. 1995). Regarding air pollutants and GHG emissions, the environmental space in question is the capacity to absorb pollution.

4. Case Studies

4.1. Puerto Viejo

Puerto Viejo is a coastal town in Costa Rica, located in the canton of Talamanca, Limón. Talamanca is the second largest canton in the country, with an area of 2,810 km^2 (INDER, 2014). The temperatures vary between 21 and 29°C (Weather Atlas, 2022). According to the last national population census, in 2011 the district of Cahuita, where Puerto Viejo is located, was Talamanca's most populated district, with 8,861 inhabitants. Of that population, 56% self-identifies as white or mestizo, 14.7% as indigenous, 12.5% as bi-racial, 10.7% as Afro-descendant, and 0.5% as Chinese (INEC, 2011).

The canton of Talamanca contains at least 11 spaces for the conservation of natural resources (INDER, 2014). The Cahuita National Park and the Gandoca-Manzanillo Wildlife Refuge have positioned themselves as renowned tourist attractions in the area. In 2021, these two areas attracted 122,389 and 96,472 visitors, respectively (ICT, 2022). This has resulted in tourism becoming the main source of income for the coastal sector of Talamanca, where Puerto Viejo is located (Municipalidad de Talamanca–MIDEPLAN, 2014).

Even though tourism development is centered on the coast, the development conditions of the canton do not allow to take full advantage of this potential due to the poor conditions and lack of access roads, poor quality of water for human consumption, low coverage of telecommunications and energy (Image 1) (Municipality of Talamanca–MIDEPLAN, 2014). Talamanca has the second lowest cantonal human development index in the country (UNDP Costa Rica, 2021) and doubles the national average in terms of the number of households with insufficient resources (national average: 11%, Talamanca: 22%) (Municipality of Talamanca–MIDEPLAN, 2014).

The road infrastructure in the area comprises three national routes and a local road network of 585.10 km, of which 93% are gravel roads (Unidad de Gestión Vial–Municipality of Talamanca, 2016). There is one bus route providing bus services to the Cahuita, Puerto Viejo, and Manzanillo areas from San José, one from the central canton of Limón, and one providing connecting services between

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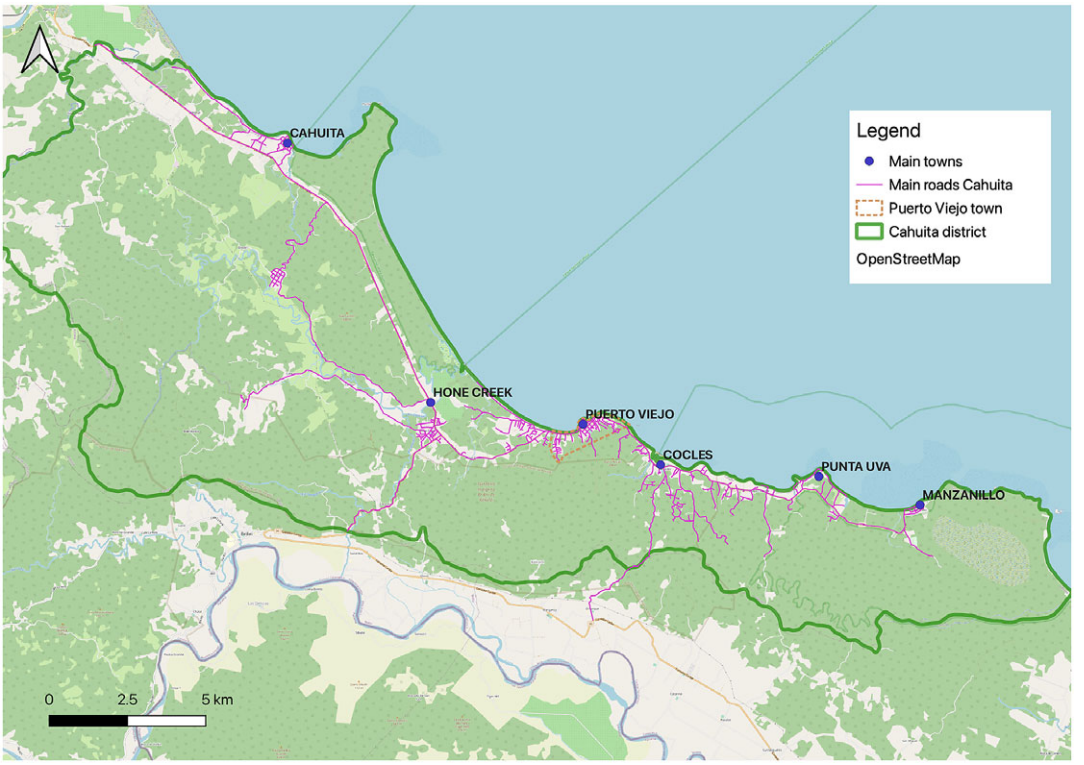
Image 1. *Puerto Viejo's main roads.*

Puerto Viejo and the Bribri area, where the local government is located. Other routes existed, but these have been merged under one company, and others have been closed recently (MIVAH, 2013; CTP, 2022). Bus service hours are very limited, direct services to San José are only available once a day, and the maximum frequency for routes that connect to Puerto Viejo is once every hour between 4 AM and 6 PM during weekdays and less frequent on Sundays. The service to Bribri operates between 5 AM and 6 PM, usually every other hour or every two hours. There are no bus services in the area after 6 PM. Formal taxis can be found, though the offer is very limited. According to data from the Public Transport Council, only two authorized taxis provide transport services in Puerto Viejo (Map 1) (CTP, 2022).



Map 1. *Main roads and towns of Cahuita district where Puerto Viejo is located.*

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4.2. Soledad

Located in the Caribbean Region of Colombia, Soledad is a medium-sized city, home to more than 600,000 inhabitants that live at an average temperature between 25 and 30°C. It is the sixth largest city in Colombia and the third on the country's Caribbean coast. The area of Soledad spreads over 67 km^2 with an average population density of 8,999 inhabitants per square kilometer. In 2018, 51% of Soledad's inhabitants were women, 70% were between 15 and 64 years old, with more than half the population (55%) between 15 and 50 years old (Table 1). The percentage of the population self-identifying with ethnic minorities has decreased since the last national population census, rising from 3% in 2005 to 1.4%, with 1.3% identifying as Afro-Colombian. Most dwellings in Soledad are not overcrowded (more than 3 people per bedroom); most have access to piped water and electricity and are connected to the sewerage system. According to the last national population census, 2.3% lived in overcrowded conditions, 10% in dwellings lacking access to sewerage, 1.45% without piped water, and 0.5% without electricity. Despite having relatively high access to public utilities, most of Soledad's neighborhoods are classified by the Colombian Statistics Agency as "socio-economic stratum" 1 or 2 (96.6%). In Colombia, socioeconomic strata offer a proxy variable for household income (Cantillo-García et al., 2019) ranging from 0 to 6 based on the physical characteristics of the dwelling (e.g., building materials, access to basic utilities, flooring) and immediate surroundings (pavements, access roads) with 0 being undetermined and 1 the lowest level of income. Less than 1% of the population lives in dwellings classified above economic stratum 3 (0.06%) (see Map 2).

Soledad is part of a conurbation with Barranquilla, the fourth most populated municipality in Colombia and the nucleus of the metropolitan area. The conurbation has played a major role in Soledad's transport infrastructure, particularly following the development of a Bus Rapid Transport System. Soledad's urban mobility infrastructure is characterized by the dichotomy of hosting major metropolitan (bus terminal and international airport) and national transport infrastructure and numerous unpaved narrow roads. The national-level highway that divides the city in two and the distribution of BRT trunk and feeders and bus routes illustrate the priority given to connectivity with Barranquilla (the main city of the metropolitan area) over local mobility. The latter comprises motorcycles (15% of journeys), active travel modes (3% and 39% in peripheral neighborhoods), and since 2002, MTW (12%) (Nieto-Combariza, forthcoming). In 2008 the use of MTW for public transport was banned by the national government in municipalities with over 50,000 inhabitants. The Ministry of Transport Decree (4125) disregarded the diverse roles MTW had acquired in some urban areas in the country, particularly in Soledad, without any public document or declaration to justify the limitation of this form of transport to municipalities with less than 50,000 inhabitants.

5. Methodology

To identify the uses and the characteristics of the operation of MTW, the methods in Soledad and Puerto Viejo encompass surveys (online and in situ), interviews with drivers and stakeholders, and a mix of

Table 1. *Determination of the emission factor*

Category	Model	Performance (km/gal)	Efficiency (gal/km)	Type of fuel	Emission factor (kg CO_2 eq/gal)
Car	2015	60	0.017	Gasoline	8.15
Bus (C2)	2011	28	0.036	Diesel	10.15
C2L	2011	29.5	0.034	Diesel	10.15
C2G	2021	11.5	0.087	Diesel	10.15
C3S2	2020	5.5	0.182	Diesel	10.15
C4	2020	5.5	0.182	Diesel	10.15
C5	2020	5.5	0.182	Diesel	10.15
Motorcycle	2020	100	0.01	Gasoline	8.15
Motorized three-wheelers	2015	80	0.013	Gasoline	8.15

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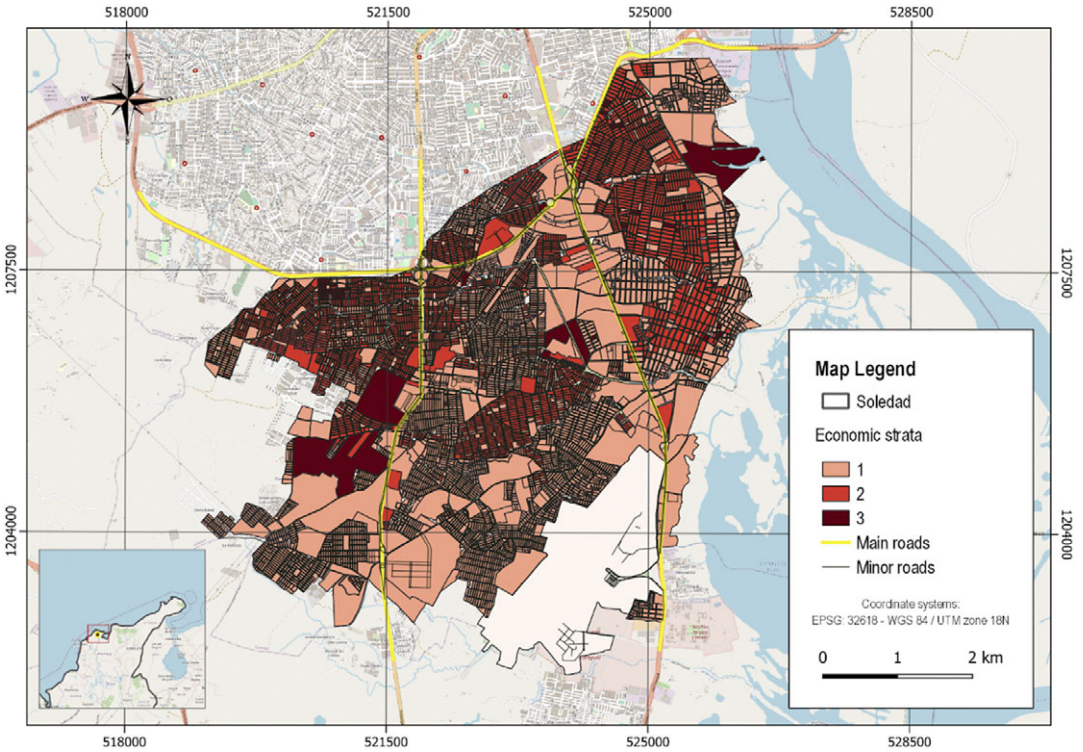

Map 2. *Soledad location, main roads, and economic strata distribution.*

low-cost technology-supported methods to generate geolocated data. The low-cost methods had a two-fold aim. First, less time-consuming and resource-demanding methods are preferable in the context of problematic perceptions and regulatory grey areas. Second, the differences in size and consolidation of MTW in the two case studies allow us to test the methods and identify their potential application to other contexts with limited data and resources. For the surveys, the sampling strategies were designed considering the different dimensions of the two case studies and the availability of geolocated sociodemographic data.

5.1. Surveys

In Puerto Viejo, an online survey collected data on users' experiences with and perceptions of MTW services. Using Google Forms, 148 surveys were sampled from the area's population of 8,861 (INEC, 2011), offering a 95% confidence level and an 8% margin of error. The survey was disseminated via social media, WhatsApp, and physical venues, and designed to accommodate both English and Spanish speakers. Questions were based on a previous Soledad survey, adapted to the Costa Rican setting and online format.

A separate survey targeted local businesses, seeking insights into their interactions with and usage of MTW services. The sample was sourced from members of the South Caribbean Tourism and Commerce Chamber and distributed through similar channels as the user survey.

The Soledad survey employed a two-level stratification process, ensuring representation across six sociodemographic attributes (gender, age, socioeconomic strata, birthplace, disabilities, and ethnicity). The resulting sample spanned 134 out of 136,134 city blocks, as per the 2018 population and housing census, with 515 completed questionnaires. Surveys were administered in person by a two-person team over several months. Data were subsequently coded into a unified database.

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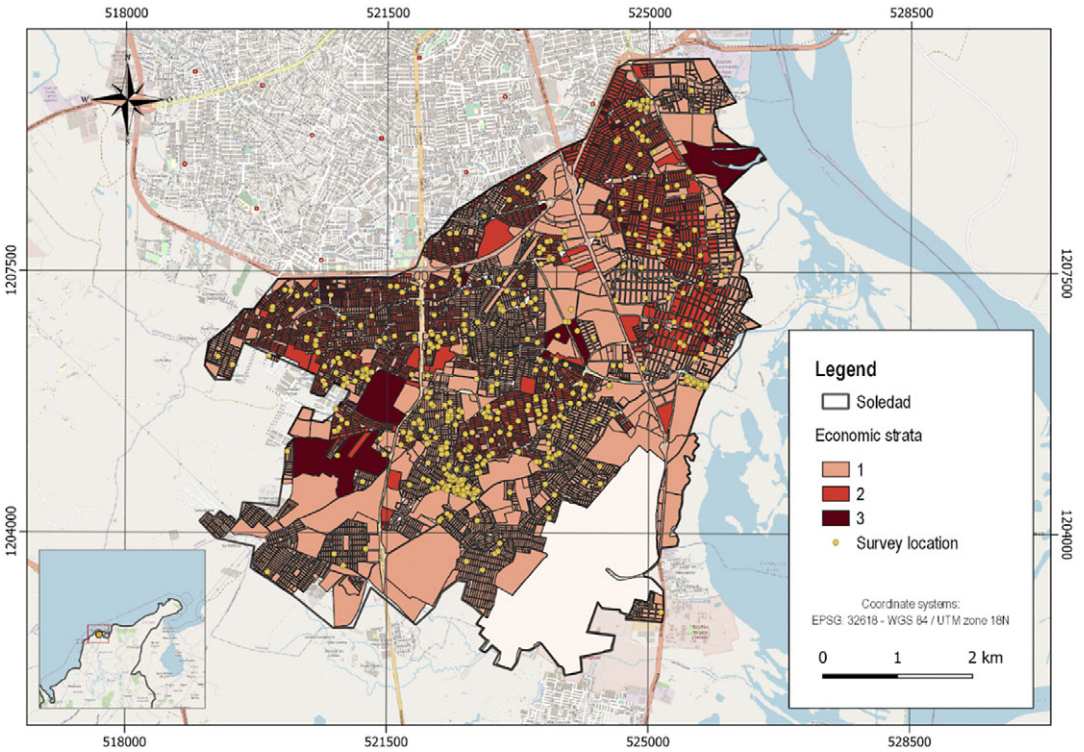

Map 3. *Survey/origin locations – Soledad.*

The research sought to understand the demographics of MTW users, the nature of their travel, and their experiences compared to other mobility options in Soledad and Puerto Viejo. The Soledad survey captured the area's demographic heterogeneity (see Table 1), providing a representative snapshot of travel behavior and mobility patterns. Surveys in both regions included questions related to travel behavior and user experiences, inspired by the findings of Marquez (Márquez, 2017). Responses were processed and analyzed to align with the research's objectives. In Puerto Viejo, trip mapping was accomplished using origin-destination data collected through the survey, driver focus groups, and interviews.

In the case of Soledad, the questionnaire also collected geospatial information: the coordinates of origin (sampled dwelling see Map 3) and destination (attraction zones). The team used the geolocation feature in WhatsApp to map the origin. According to Oviedo et al. (2022), WhatsApp geolocation accuracy depends on the phones' characteristics, with an average error of between 3 and 10 m. The geocoding of the destinations resulted from converting the addresses or reference points in the surveys into geographic coordinates with Google My Maps.

The mobility surveys in Puerto Viejo and Soledad were first explored through descriptive statistics. In Soledad, through the geolocation of the origin-destination pairs in the survey, we defined the start and end points for the measurements of exposure to air pollution.

5.2. Sensors

Recently, the use of low-cost Air beam sensors to measure PM2.5 has increased research about exposure to air pollution in urban mobility. Ma et al. (2020) showed how smart technologies and individual activity-travel microenvironments affect the assessment of individual-level pollution exposure in space and time at a very fine resolution in different modes: car, metro, and walk.

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In China and the United States, Air beam units were used for spatial modeling of particulate matter air pollution sensor measurements collected by community scientists while cycling, land use regression with spatial cross-validation, and applications of machine learning for data correction; feasibility and acceptability of monitoring personal air pollution exposure with sensors for asthma self-management (Adams et al., 2020; Guevara-Luna et al., 2020; Xie et al., 2021). Although air sensors are not a replacement for regulatory monitors, they entail a valuable teaching tool (Anastasiou et al., 2022). The data may help the general public better understand the air quality in their communities.

The air quality measurements were carried out to identify pollutant exposure while riding an MTW. The trip route was determined based on the insights of the MTW drivers and the O-D information collected. In Puerto Viejo, the route selected is the most common for trips in MTW during the day and night, as well as on weekdays and weekends. The starting point was the MTW station at the corner of the Hot Rocks restaurant, and the return point was Punta Uva Beach. The measurement is constant until returning to the starting point. In Soledad, seven sub-zones were delimited. The division was made considering the spatial distribution of the reported trips in the survey, the land use, and the main roads in the area. The O-D of MTW users in the survey was distributed in these zones. In Soledad, the road network monitored during two periods, the morning peak on a weekday and the weekend, represents 10.5% of the local network. During the sampling, the users of the MTW indicate to the driver their destination, letting the driver decide the route. In both cases, during the air quality measurement, a field diary was kept to register eventualities or situations that might contribute to changes in measurements, such as construction sites, changes in road quality, congestion, or vehicles on the road.

5.3. Geolocation

In Puerto Viejo and Soledad, we identified "stations" and hubs where different groups of MTWs operate. In Puerto Viejo, the stations were identified based on online information, mainly Facebook pages where MTW services are advertised or tourism sites that provide information about how to use these services. Common origin and destination sites were identified through the user survey and records provided by some of the tuk-tuk operators. In Soledad, we used Google Street views and the data from the surveys to identify the location of MTWs' parking areas and the distribution of the origin and destination of the travelers in the surveys. Additionally, the identified locations were confirmed and complemented by the interviews with MTWs' drivers and site visits.

The most likely routes were estimated using My Map, and the information about origins and destinations was compiled in each case. The GPS information from the air quality sensor complements this information.

5.4. GHG emissions estimation

Emissions were calculated for the working day of a motorized MTW driver, and these calculations were performed using the Greenhouse Gas Protocol (2013) methodology and the Auto-Data (2020) database. The fossil fuel quantity approach described in the technical guide's upstream transport and distribution section was applied. These emissions are calculated by multiplying the average distance traveled in a day, the average vehicle fuel efficiency data,[1] the corresponding emission factor, and for CH_4 and N_2O, the global warming potential to obtain a total of CO_2 equivalent (Eq. 1). The data and considerations taken for this calculation are included in the Appendix.

[1] The vehicle fuel efficiency data are theoretical values. Variables such as vehicle age, maintenance, fuel quality, driving technique and even atmospheric conditions might alter this efficiency. When using theoretical values in the calculation of emissions for both MTW and taxis, these variables are unaccounted for and left unchanged. To make the calculation more precise in future exercises, tachometer readings and fuel-filling records can be collected for a certain period to acquire an average distance and fuel use.

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Table 2. *Comparative GHG Emissions per vehicle per day according to different vehicle typology scenarios*

Motorized three-wheelers	Existing taxis in Puerto Viejo	Sedan automobiles
Bajaj (2022)	2006 Peugeot Partner 2010 Daihatsu Terios 2009 Mitsubishi L200	Toyota Yaris (2022)
9.54 kg CO_2 eq per vehicle per day	19.2 kg CO_2 eq per vehicle per day	14.8 kg CO_2 eq per vehicle per day

$$\text{emissions} = \text{average distance travelled}\,(\text{km}) \times \text{vehicle fuel efficiency}\,(\text{km/L}) \times \text{emission factor}\,(\text{kg}CO_2\text{L}) \quad (1)$$

In Soledad, the distance traveled by vehicles was estimated by using a set of 53 different traffic counts around the city to estimate GHG emissions. The traffic counts were divided into four road types: arterial, collector, residential, and service. Additionally, five categories of vehicles were considered: car, bus, truck, motorcycle, and MTW. The team calculated the average peak hour volume for each road category (vehicles per hour) and we worked on the assumption that this value behaves similarly for roads in the same classification. In addition, we assume the average daily traffic was about 15% of the peak-hour volume. Finally, with the total length of each road category within the Soledad transportation network, an approximation of the distance traveled by each vehicle was obtained.

Vehicle efficiency was calculated based on performance (km/gal). The average performance of each vehicle category was defined based on an experimental campaign developed in 2021 by the Mining and Energy Planning Unit–UPME, in which the following variables were considered: model year, most representative brands, and emission control technologies in the country, as well as the driving cycles used for each vehicle category. Similarly, the emission factor for CO_2 was determined based on the type of fuel used by each vehicle type according to that developed by the UPME for Colombia (Table 2). Generic gasoline is 8.15 kg CO_2 eq/gal; generic diesel is 10.15 kg CO_2 eq/gal (records are included in the Appendix).

5.5. Comparative analysis

The second stage was completed by the two teams developing a staggered comparative analysis of the two cases. Inspired by the transnational approach (Roy and AlSayyad, 2004) and following Robinson's (2016) proposal to "thinking cities/the urban through elsewhere," we use the two cases to think comparatively, highlighting the differentiation of current conditions of three-wheeled mobility. We use "questions and answers generated at one site to more substantially interrogate other, fundamentally different sites" (Roy and AlSayyad, 2004, p. 22). The comparison of Soledad and Puerto Viejo, two urban areas of very different sizes (population and area wise), brings into light the distinctiveness of each case and the shared characteristics of the form of mobility under study. The comparison of these two cases is a comparison of an urban process and experiences avoiding restricting variation-finding methods to relatively similar cities (Robinson, 2011). The comparability of the cases is based on the relevance of mobility in MTW as a comparator or as the "third term", the term that enables to relate two processes and experiences (Jacobs, 2012; Robinson, 2016).

6. Findings

This section examines the impact of MTW on urban connectivity in Puerto Viejo and Soledad. It analyzes MTW users based on six sociodemographic and economic indicators, focusing on the role of MTW in

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mitigating inaccessibility and social exclusion. It investigates how MTW increases access to essential activities and mitigates various forms of social exclusion. Additionally, it evaluates the environmental sustainability of MTW. The disparity in scale and urban development paths of the two case studies forms the foundation for comparing their respective findings. This process serves to underscore distinctive attributes of MTW associated with the dimensions and functions within each context, while also accentuating the shared elements that persist despite the differing characteristics of each individual case.

6.1. Contributions to accessibility and to overcoming instances of social exclusion

In Puerto Viejo, most of the people who responded to the online user survey were women (63%), people between 25 and 34 years (37%) and identifying themselves as Latin (52%), White (22%) and Mestizo (18%). However, there were also responses from people identifying as Afro-descendant (7%), Indigenous (0.7%) and Chinese (0.7%). The survey's low percentage of the indigenous population responds to their location in several Indigenous Territories on the outskirts of Puerto Viejo, the closest being the Keköldi Territory. Such limited representation of a specific social identity due to their location highlights the importance of future research of considering in the methodology the location and/or digital accessibility of particular populations to secure their inclusion in the process of data collection. Questions about education and income level were answered only by 8% of the sample. The majority of the participants who responded to these questions have a university degree and enough or more than enough resources to cover their basic needs. The digital nature of the survey entails less information about people with lower income levels and less access to higher education who tend to have less access to the internet and time to engage in non-income related activities. Similarly, there were no respondents who reported having any form of disability. Most of the respondents are Costa Rican residents, closely followed by people who have visited Puerto Viejo as tourists and residents who are not Costa Rican.

More than half of the respondents (66.8%) have used MTW, 63.6% of which are women, 44.4% live in Puerto Viejo and are Costa Rican, 27.3% live in Puerto Viejo but are from another country, and 21.2% are tourists. The user's age range is predominantly between 25 and 44 years old (58.7%), and 17.2% are between 18 and 24 years old. The lower representation of older users might also be a consequence of the survey being online. MTW are not combined with other modes of transport, showing they work as principal modes of transport (Figure 2).

In Soledad, the socioeconomic characteristics of the surveyed population are similar to the distribution in the 2018 Population and Housing Census (DANE, 2018) with some characteristics related to conditions of social exclusion such as disabilities and minorities being overrepresented (see Appendix for the % census data vs. survey). The majority of individuals surveyed did not identify with any ethnic group (40.27%), and a third of the survey respondents identified themselves as Mestizo (37.74%), followed by Afro-descendant (11.48%) and White (8.37%), with 2% identifying as Indigenous. About 51.75% of the respondents identified as women, and 0.19% identified as trans. The totality of the sample was in households classified in economic strata 1 and 2 and 2% in strata 3. Accordingly, nearly two-thirds of the population declared their monthly income to be just enough to cover their basic needs, 25% considered having more than enough, and 5% went a day or more without eating for lack of money. Half of the respondents who missed a day or more meals also had children. One-third of the respondents have as their main activity to do household work, and one-third have a job with a written contract, 10% without a contract, and 10% said to be self-employed. The living conditions of the population surveyed are varied. Close to half own the house they live in, 35% with property title (35%) and 12% without. The remaining respondents live with family or friends (26%) and rent with a contract (13%) and without a written contract (13%). Less than 2% of the respondents live in houses with floor materials considered inadequate by the Ministry of Housing in Colombia. Close to half of the respondents (49%) do not have children living with them, 22% have 1, and 19% have 2. 51% of the individuals in the sample are heads of their household, with 58% of these individuals self-identifying as men and a quarter being single-headed households (Figure 3).

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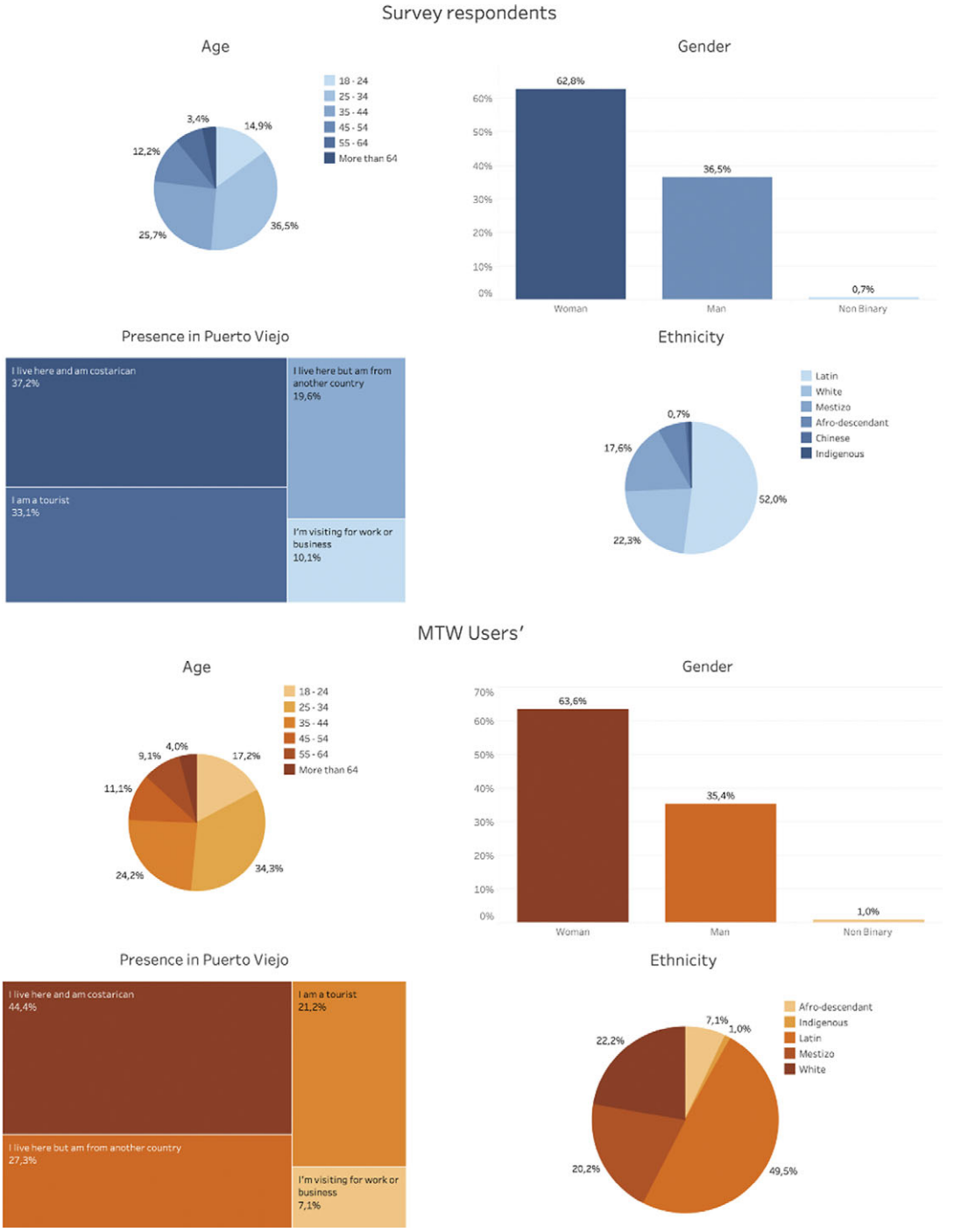

Figure 2. *Dashboard of respondents and MTW users' characteristics in Puerto Viejo.*

All the surveyed inhabitants have used MTW at least once in their lives, and 14% use these vehicles as their main mode of transport. Users of MTW as the principal mode of transport combine it with walking (42%) or use it exclusively. Only 1% of the respondents combine their main mode of mobility with another use of MTW. Half of this 1% of users of MTW as a complementary mode are bus users, and a third are

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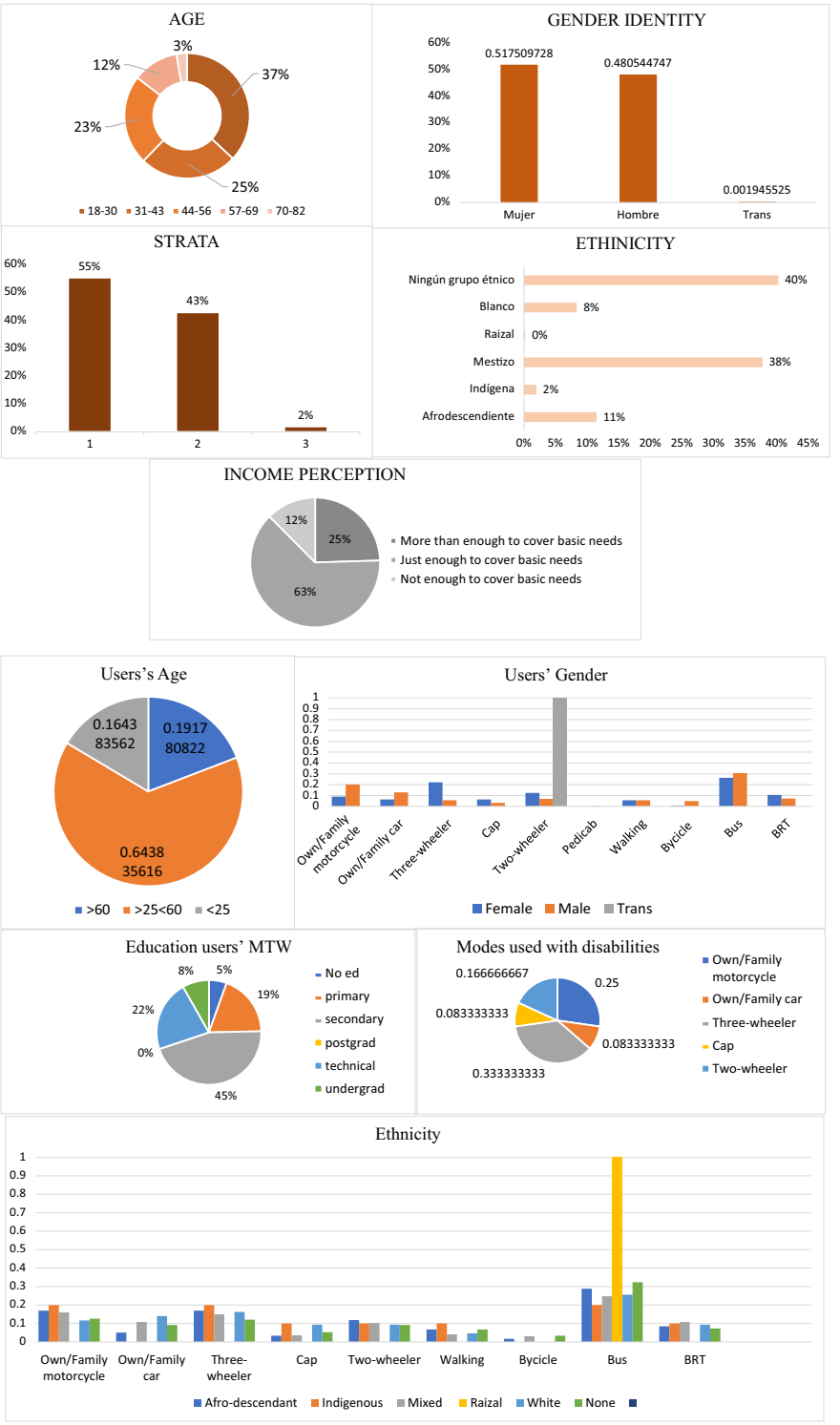

Figure 3. *Dashboard of respondents and MTW users' characteristics in Soledad.*

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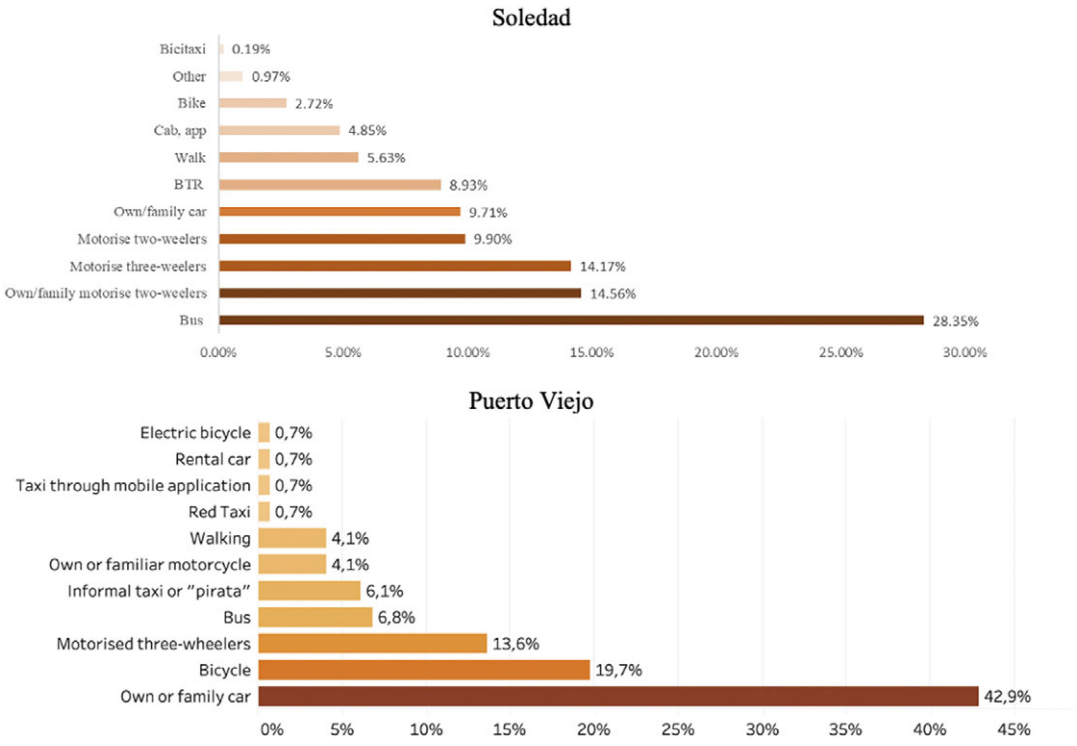

Figure 4. *Distribution of the most frequently used mode of transport in Soledad and Puerto Viejo.*

motorcycle taxi users. The majority of users are women (80%), and the main activity is running errands (57%), followed by work (21%) (16% with contract, 6% without contract), leisure activities (9%) studying (5,8%). A third of the respondents with disabilities are MTW users. Regarding the other sociodemographic characteristics, the distribution is similar for all the transport modes: around 40% of MTW users identify as Mestizo, 33% as none, and there is some variation in users, 10% more MTW users identifying as Afrodescendant instead of White compared to other modes. Around 19% of users are older than 60 years old or younger than 25, and 66% are between 25 and 59 years old. Regarding education, 20% of respondents with primary education use MTW, and a similar percentage uses the bus (25%). Inhabitants with university and postgraduate degrees use predominantly private modes (73%).

Regarding modal share, MTW were the third preferred option for daily travel in Puerto Viejo (13.5% of respondents reported this is their main travel mode) and Soledad (14.17%). While in Soledad, buses are the most used transport mode (28.35%), buses in Puerto Viejo were the least used (6.8% of responses), and travel by private car is the mode of transportation of 42.6% of the surveyed. The second most used mode in Puerto Viejo is the bicycle (20%), while in Soledad, they are private motorcycles. In relation to other small-capacity modes of transport that exist in grey regulatory areas, like "pirate taxis" in Puerto Viejo (6%) and motorcycle taxis in Soledad (9%), MTWs are more used in both areas (Figure 4).

Trip length in MTW is generally short. More than half of the trips in tuk-tuks were between 5 and 10 min, and only 8% took more than 15 min (Figure 5). According to the trips recorded by the MTWs in Soledad and users' responses, the average distance of the trips is 5.5 km. Similarly, in Soledad two-thirds of the trips are less than 20 min, and only 11% are longer than 30 min. Regarding frequency, most responses show that MTW are used several times a week, or at least once a week and several times a month. In Puerto Viejo, there are also a lot of occasional users and people who have only used the MTW once. This could be explained by the number of tourists who answered the survey and might have only used the MTW while visiting Puerto Viejo.

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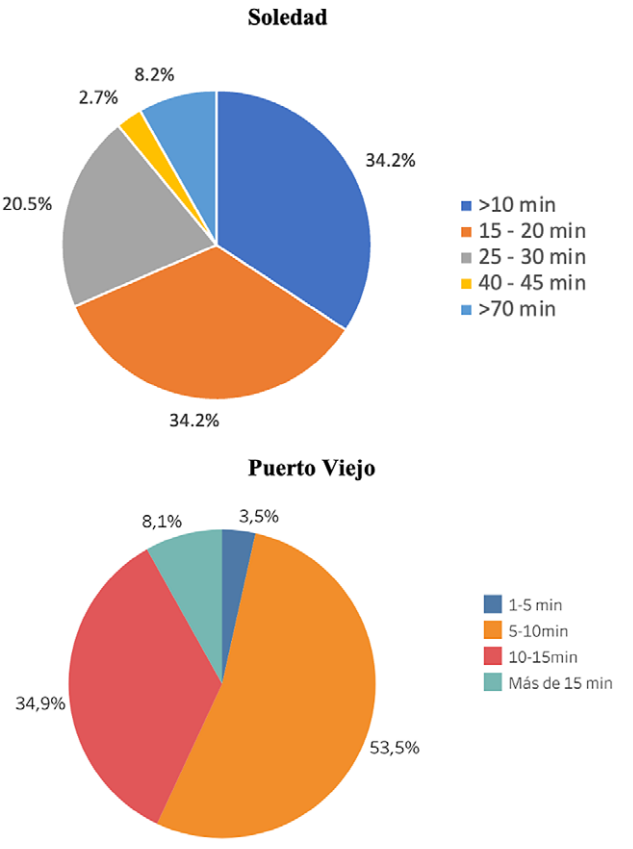

Figure 5. *Length of trips taken on MTW in Puerto Viejo and Soledad.*

6.1.2. Geographical and temporal access

To evaluate the relation of MTW to the fragmentation–inaccessibility–exclusion process, we start with the geographic and temporal distribution of this form of mobility in the two case studies. The types of trips that are characteristics of MTW users are also interpreted as indicative of their function within this process of fragmentation-inaccessibility and exclusion from the geographical and temporal dimensions of exclusion. Additionally, we consider the rationale of MTW in choosing this form of mobility to understand their functionality further.

The similarity of uses of MTW in the two case studies considering the different scales and urban trajectories highlight the predominant role of MTW in complementing higher capacity public transport with short, frequent, and flexible trips that enable access to otherwise inaccessible locations. In Puerto Viejo, buses are the only form of high-capacity public transport, with the central bus station close to the beach line. Buses have regional destinations, including San José (Costa Rica's capital) the center of the province of Limón, and other areas such as Cahuita, Sixaola, and Manzanillo. Taxis and MTW are the other two forms of public transport. In contrast, access to taxis is limited as there are only three authorized providers, and two MTW stations are located in the two extremes of the city's core. The distribution of destinations all around the surrounding area of Puerto Viejo shows their geographic coverage (Map 4), The main destinations for MTW trips are the towns around Puerto Viejo, many of which have beaches, hotels, and other attractions. Also, many trips are made to downtown Puerto Viejo. The workshop with MTW drivers, the user survey, and records from the MTW providers and MTW Call Center show that MTW services provide access to places in the Puerto Viejo area that are not connected

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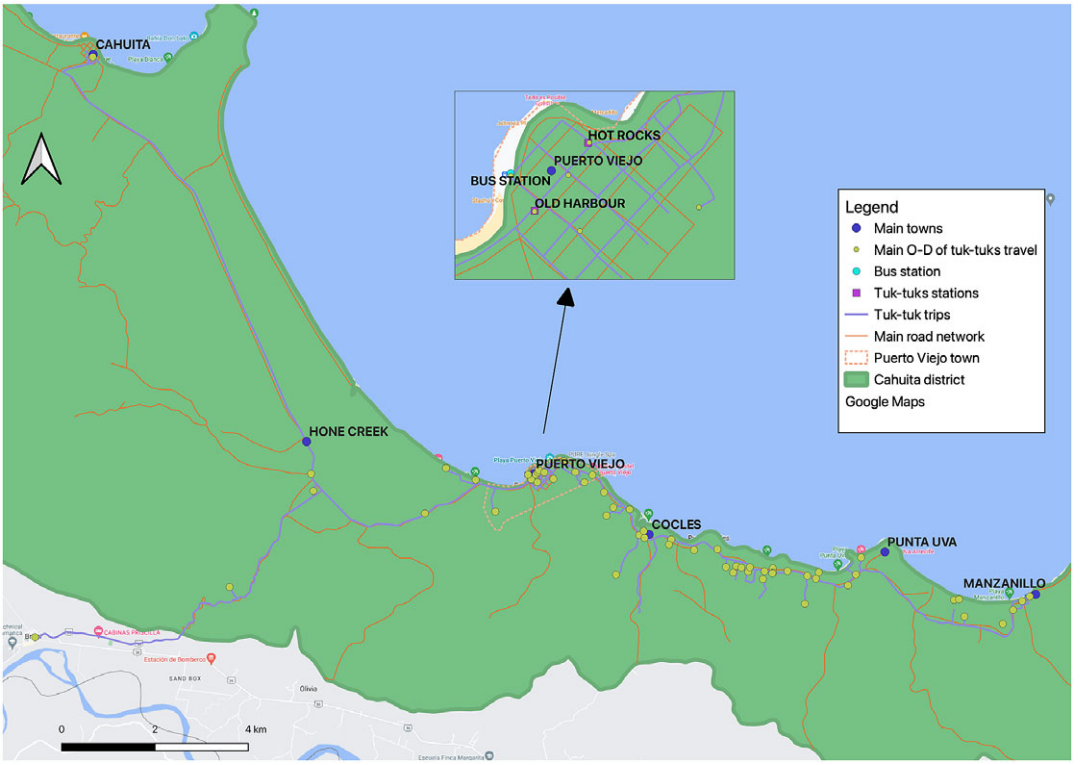

Map 4. *Main points of access and destinations of public transport in Puerto Viejo and surrounding areas.*

by bus services. These include, for instance, gravel roads that connect the beach area to hotels or restaurants that are deeper into the mountain area (see Map 5).

In Soledad, high-capacity public transport includes a Bus Rapid Transit (BRT) trunk, feeder routes, and collective bus providers. Three BRT stations are fed by twelve feeder routes running from 4:45 or 5 AM to 9:40 or 10:38 PM on weekdays from east or west to the trunk that divides the city into two areas (*Map 5*). Soledad's collective buses run predominantly from north to south and back, with only two routes connecting the city's east to west (Map 6). It is also possible to see in the destinations of users of public transport modes other than MTW (i.e., bus and BRT) that most trips are directed outside Soledad (Map 7). On-demand, intermediate capacity services include MTW, motorcycle taxis, and taxis. In Soledad, these modes have no specific stations but the main hubs identified were located outside all four major shopping malls and chain supermarkets and the three BRT stations. Based on the user survey, the coverage of MTW shows predominantly trips that connect the east to the west, excluding the most western parts of the city. Based on the sights from fieldwork, the review of Google Street View, and the mapping of origins and destinations of respondents of the survey that use MTW as their main transport mode (Map 8), it is possible to argue that MTW increases Soledad's connectivity, thus contributing to reduce geographical conditions of exclusion.

Regarding temporal access in Soledad, it is important to note that the mobility of respondents in the sample is characterized by the flexibility of leaving and returning journeys (71%). Based on the schedules of MTW users (Figure 6), we identified positive contributions of MTWs to the temporal accessibility of Soledad's inhabitants that require services before and after the bus and BRT start operating. The positive contribution to temporal access is stronger in the case of Puerto Viejo. Considering the limited-service hours for the bus operation (see Appendix), where maximum frequencies are of one service per hour, and the latest hour being 6 pm, the availability of MTW increases access to transport services throughout the

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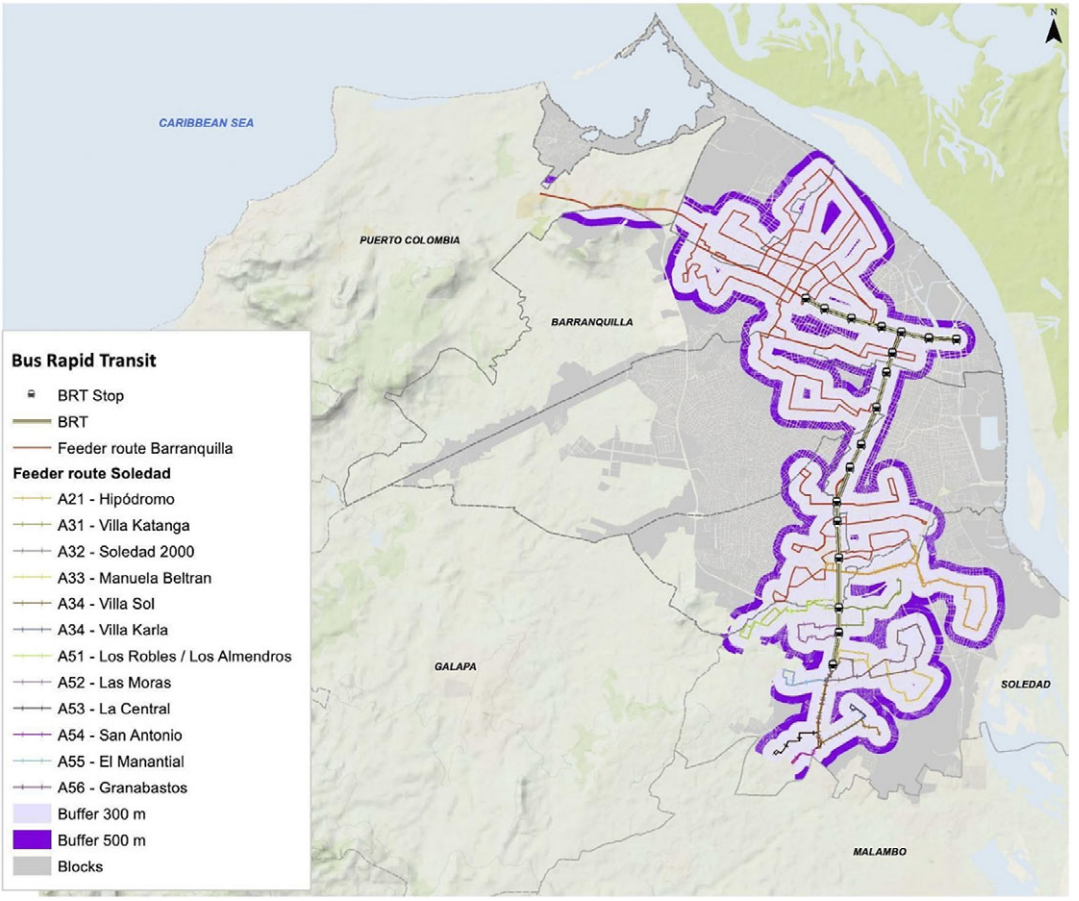

Map 5. *BRT trunk and routes 300 and 500 m buffer access.*

day. There are few taxis available in the area, and they seem insufficient for the local demand. In contrast, the two MTW stations identified where 35% of respondents to the survey accessed the service, always had vehicles available and there was a call center that provided services at all hours. There are also options to coordinate trips using WhatsApp (26.3% of respondents) or via cell phone calls (14%). Similarly, the rationale given by the respondents of the surveys in both cases shows that the contribution of MTW to temporal and geographic access is stronger in Puerto Viejo. In the case of MTW users in Soledad, short distances (25%) and comfort (22%) are the main reasons to choose these vehicles as the main mode of transport. Less than a tenth of Soledad's MTW users (7%) chose "no having any other option" as their reason to use this mode. In Puerto Viejo, the reasons most respondents use MTW are because they are convenient (45%), it is fun to drive them (40%), and to travel short distances (40%).

In both cases, MTWs improve the integration and connectivity to existing public transport services. In Puerto Viejo, MTW reports show that a common trip is early morning runs (between 4 and 6 AM) to take passengers to the local bus stop to take the only bus service to San José or the early services going to Limón. In Soledad, three major hubs are the BRT stations. However, in Puerto Viejo, MTW services are mainly in the surroundings of Puerto Viejo's urban area, and most trips are roughly 5.5 km long. As a result, the population segregated from urban areas, predominantly indigenous people use these services only sporadically to come to Puerto Viejo for special events or run errands. The very few registers of trips to the areas where the indigenous population is located point to their reliance on other transport modes as well as lower frequency of trips. Similarly, in Soledad, in the north-west and south-west parts of the city,

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Map 6. *East–west routes identified in Soledad.*

where less consolidated neighborhoods are located- the origin-destination map (Map 8) has fewer observations, pointing to a coverage limitation in the contribution of MTW to reduce geographical exclusion. During informal conversations with drivers, some mention that these areas are avoided because of the state of the roads or safety concerns.

6.1.3. Facilities

Access to livelihoods and place of study. In the two case studies, MTW have an essential role in connecting people to their livelihoods and where they study. In Puerto Viejo getting to and from work is mentioned by users as one of the main purposes for using MTW. Drivers of MTW mentioned that frequent destinations outside of Puerto Viejo town are Hone Creek and Cahuita for workers. Considering the limited availability of bus services in the area, MTW become the main transport mode, and an alternative to ensure access for users without access to buses because of the limited frequencies and operation hours of the buses. A third of the respondents in Puerto Viejo that use MTW use them several times a week, pointing to the regular use of this mode of mobility. In Soledad, 60% of the respondents who go out of their houses daily do so to go to work and do it more than five days a week (65%). For 37% of people that going to work is their main travel purpose, MTW is their main mode of transport. the functionality of MTW in Soledad to access livelihood is also captured in the reasons for using this form of mobility. For ¼ of the chosen reasons for using MTW is to go to work (self-employed, employed with a written contract and without a contract).

In Puerto Viejo, we found no evidence of tuk-tuks being used for traveling to study. In Soledad, 5% of the MTW users stated studying as their main activity at the destination where the MTW took them. Some drivers mention having primary and secondary students as fixed clients. During site visits, it was common

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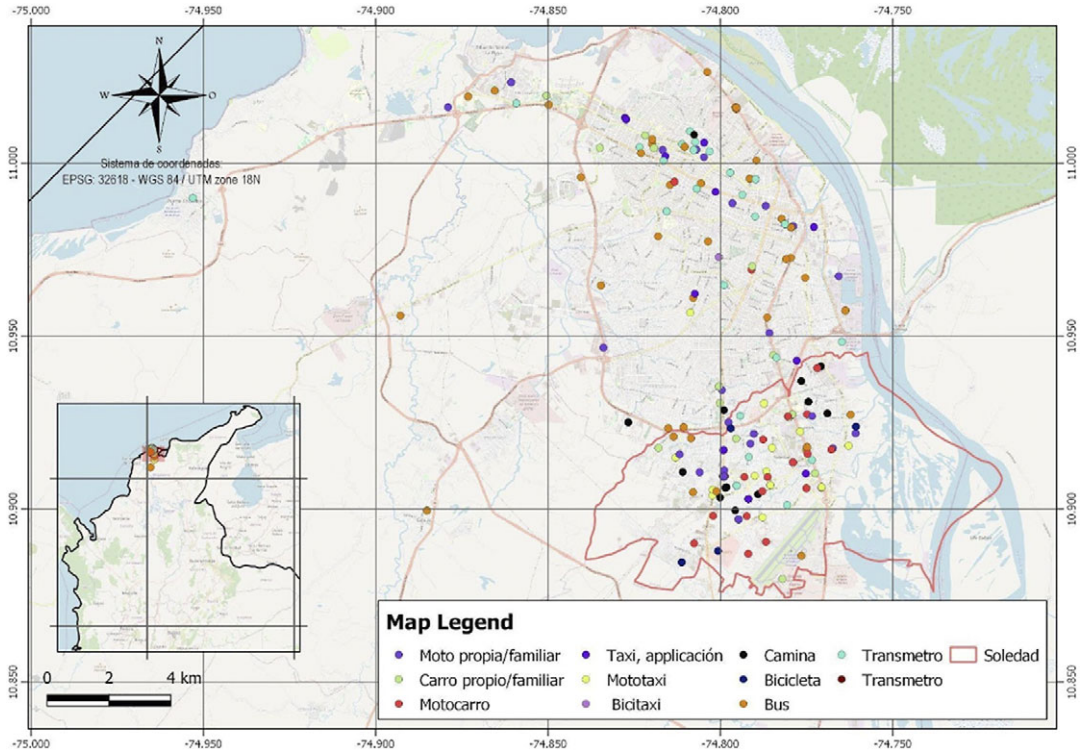
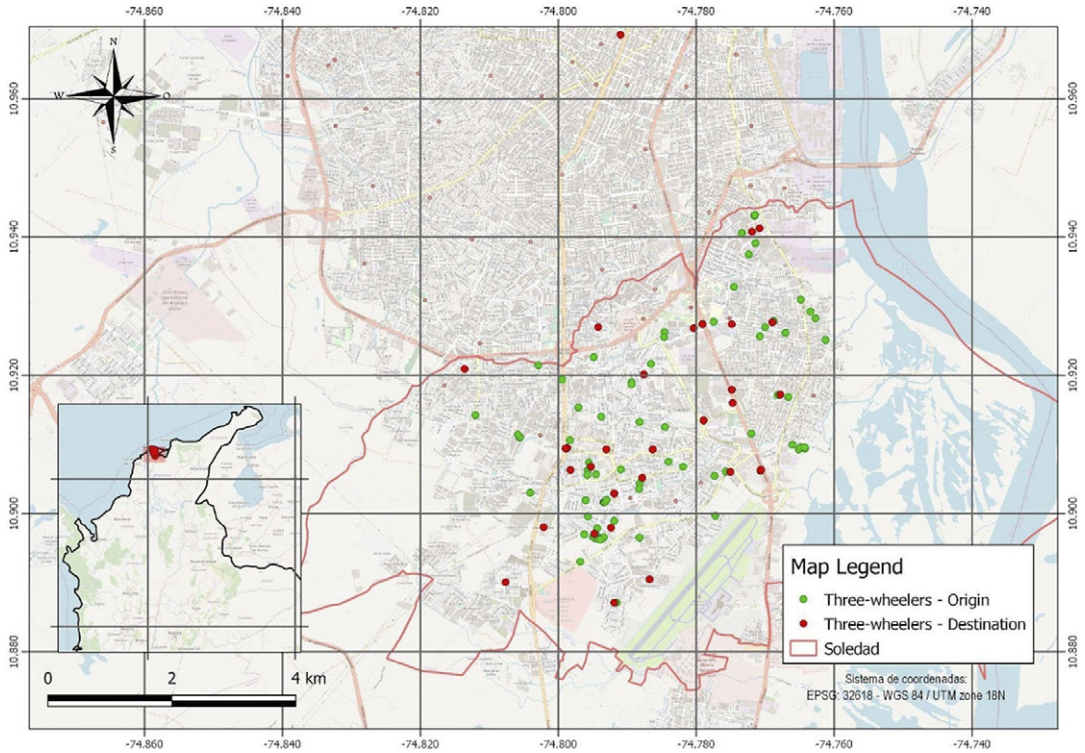


Map 7. *Origin-destination of all transport modes in Soledad.*



Map 8. *Origin-destination users of MTW as the main mode of transport.*

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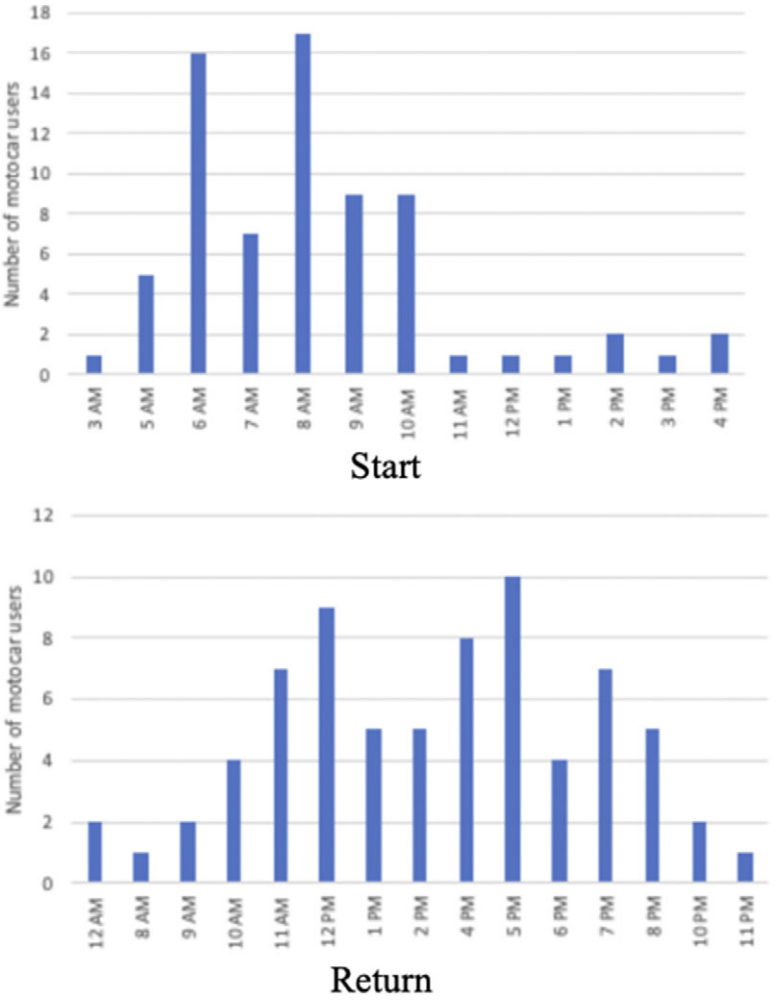

Figure 6. *Hours of travel of MTW users in Soledad.*

to see MTW parked outside primary schools picking up students. However, in the mobility survey, respondents with studying as their main travel purpose predominantly use buses (66%). With the current evidence, it is not possible to establish that MTW is contributing to increased access to educational activities in either case.

Access to recreation. MTW drivers provide services to specific tourist attractions in the Puerto Viejo area that have limited connectivity to public transport either geographically or because of the operating hours of tours. When there are traffic police operations in certain areas, which can lead to MTW being persecuted, fined, or confiscated, tourists are left stranded and can lose their tours. MTW facilitate movement between beaches in the area, as well as travel between hotels that are not in the center of Puerto Viejo, and the beach areas. MTW are also especially important in providing access to transport services during the night-time, being one of the only available ways to access or return from events, parties, bars, or restaurants. This represents an essential contribution to the local night-time economy and facilitates access to recreational activities not only for tourists but also for locals.

In Soledad, interviews with drivers indicate that during the weekends their main source of demand is the local bars and billiards. Furthermore, out of the few respondents who chose recreational activities as

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their destination (more than one-third of the respondents either said not to have any leisure time or went to a nearby park for recreation), 40% were users of MTW. Considering MTW was the third most used form of mobility, the lack of availability of east-west connections and the predominance of destinations of the other public transport modes outside the city, we identify MTW as contributing to the accessibility to recreational facilities. However, only 3% of MTW users surveyed have as destination recreational activities, including visiting friends and family, and the most common recreational activity besides visiting parks is doing sports.

Access to care activities. According to the user survey in Puerto Viejo, running errands is one of the main activities for which MTW are used (60.6%). In Soledad, 33% of the respondents that go out to run errands are MTW users, and for almost half of MTW users running errands is their main reason to go out. These results are reinforced by the location of the MTW stations identified in both cases: supermarkets and shopping malls. MTW cover the demand for a practical mobility option close by for users carrying packages after shopping.

Other care activities, such as taking pets to the veterinary, were frequent trips covered by MTW in Puerto Viejo. Although many errands can be done in downtown Puerto Viejo, certain services (such as the public health clinic and certain municipal services) are located in Hone Creek or Bribri, with limited bus hours to these destinations. MTW, therefore, offer the possibility of reaching these destinations at any hour that users need or find most convenient, facilitating care trips as well.

6.1.4. Economic affordability

Identifying the function of MTW play regarding exclusion due to economic affordability of mobility is limited in Puerto Viejo to the nature of the online tool. Within the respondents, users consider that the tariffs of MTW are neither very cheap nor very expensive (35%), yielding mixed perceptions about the affordability of these services. Determining if MTW are increasing accessibility in terms of economic affordability in Puerto Viejo requires further research. In Soledad, being cheap is only chosen as the main reason to use MTW by 4% of users (Figure 7).

MTW tariffs are not regulated in Soledad or Puerto Viejo and therefore are defined by drivers and their bargaining with users. In both cases, attempts to agree on prices are not always successful. In Puerto Viejo, some drivers do not adhere to agreed tariffs. Others stick to agreed tariffs during the daytime but raise their

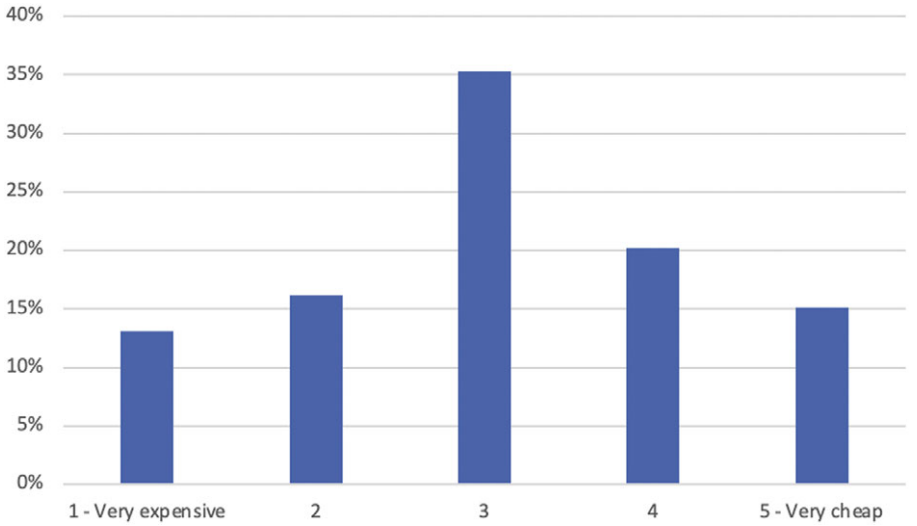

Figure 7. *User perceptions of MTW cost in Puerto Viejo.*

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prices during hours when there are no other transport options, for example at night and before dawn. An example is the early morning runs (between 4 and 6 AM) to take passengers to the local bus stop in Puerto Viejo to take the only bus service to San José or the early services to Limón. Similarly in the case of Soledad, taking MTW to get to the BRT stations increases the total cost of travel compared to using the system feeders with an integrated fare. In contrast to Puerto Viejo, bargaining in Soledad might enable some users to access mobility at a lower price when their capacity to pay is lower. However, there is also an exclusionary dimension when the driver sets a higher tariff for those users who need to access more peripheral areas. Furthermore, the tariff and use of the service fluctuate at the times of the month when salaries are paid. The fluctuation of demand to the times of the month when people have more disposable income might signal that MTW in Soledad can often be a luxury rather than contributing to accessibility through improved economic affordability. Overall, the lack of clarity or standards for tariffs poses a risk for users, as there is often no certainty about how much they will have to pay for a service and nowhere to turn if they feel they have been overcharged for it.

6.1.5. Fear of crime, harassment and injury

The operation of MTW in Puerto Viejo became mainstream in Costa Rican media after news about a case of sexual assault linked to MTW (Muñoz, 2022). The case has not been resolved but it generated a stigma for the use of these services. However, our user survey found that perceptions of safety while using these services are relatively high, with a 3.8 out of 5 average rating, and a majority of users (42%) feeling safe (ranking of 5/5) while using the service (Figure 8). Regarding fear of injury, there is no available data on road accidents, injuries, or death in the region.

In Soledad, fear of crime or harassment and road safety for users of MTW is analyzed based on four questions: how the person felt when using each mode of transport, the reason why they use the vehicle they use more frequently, the perception of safety, and the selection of the mode of the safest and most secure mode of transport. "Calm" was the feeling chosen by most MTW frequent users (28.7%) followed by "alert" (26%) and "comfortable" (20.5%). The feelings chosen by MTW users follow the distribution of the overall sample for this question. When asked about safety, three times more respondents considered that their form of mobility is safe (33%) compared to unsafe (12%). Most MTW users do not think that the mode is safe or unsafe (16% chose very unsafe and 9.6% very safe). Only 3% perceived MTW as the least likely to have an accident and 2% as the least likely to be robbed while using it. Considering the maximum

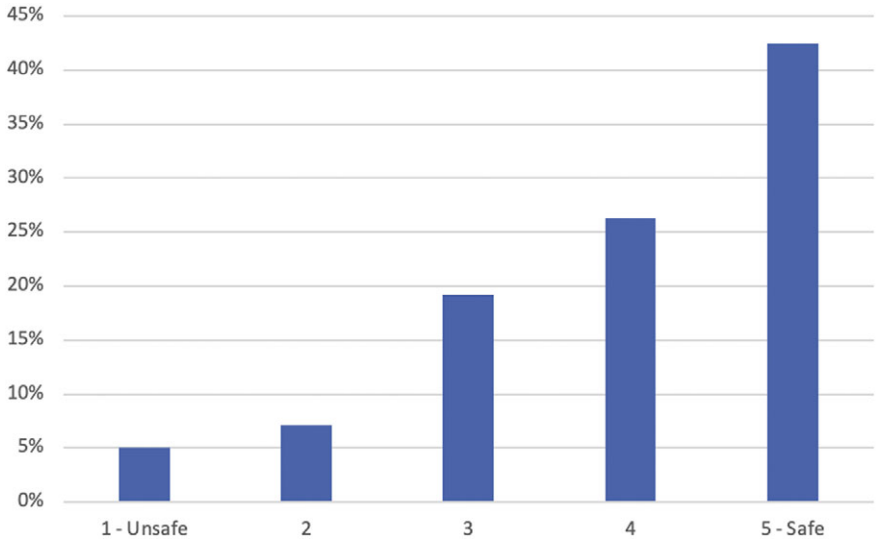

Figure 8. *Perception of safety while riding MTW in Puerto Viejo.*

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speed that MTW can reach (65 kmh) and the available data of road accidents in Soledad, from the National Police (injuries and deaths reported), MTW are arguably safer than other small-scale vehicles like motorcycles and automobiles, both for users as for other users of the street like pedestrians or cyclist. From January 2010 to 31 July 2023, none of the 298 deaths and 370 injuries reported by traffic accidents involved an MTW in Soledad. 86 of the 298 deaths involved a motorcycle and 182 involved cars.

In the case of Puerto Viejo, authorities' main response to ensuring safety while using these services is periodic traffic control operations where they confiscate or fine MTW operators (Chinchilla, 2022). When MTW suspend their operations because of police presence, people must find other alternatives to get to their destinations, often walking or cycling. The lack of safe pedestrian or cyclist infrastructure makes active mobility unsafe, especially at night. Furthermore, MTW provides services for people who want to attend a party, drink, and not have to drive back home. When these services are unavailable, they suggest there might be a risk of increased drunk driving because regulated taxis in the area are insufficient to cater to existing demand.

6.2. Environmental effects

6.2.1. Air quality

The results of the measurement of PM2.5 and PM10 show constant behavior (Figure 9), except for around the measurement time of 10:38–10:39 when the vehicle stopped to give way to several other vehicles on a narrow bridge. From 10:27 to 10:31, there was an entrance to a gravel street. This is a very visited road since it leads to one of the favorite beaches in the area. The gravel road implies the presence of more dust and particles in the measurement. This situation can happen in several secondary streets in the area due to the material from which they are made. In the first minutes of the trip, no external situation was noted down that could have caused higher peaks.

When comparing the average values obtained in this exercise with those established by the World Health Organization (WHO) (2021) and the Air Quality Regulation for Pollutants Criteria of Costa Rica (2016), the values are lower than those established as maximum. The Costa Rican regulation recommends, on average, 35 μg/m^3 for PM2.5 and 100 μg/m^3 for PM10, while the WHO recommends 15 μg/m^3 for PM2.5 and 45 μg/m^3 for PM10. With a general average value in the measurements of

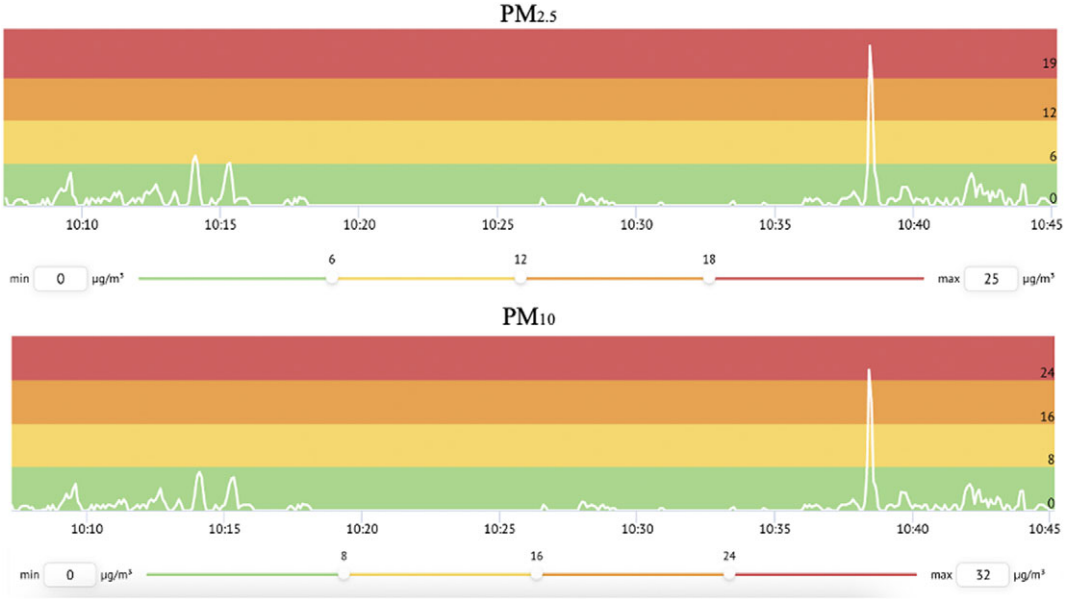

Figure 9. *Measurement of PM2.5 and PM10 in an MTW in Puerto Viejo.*

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1 μg/m^3 for both PM, the overall outcome remains within the recommended values. The fact that Puerto Viejo is a coastal town, not very developed, with low vehicle density, and the main roads where measurements were taken are very near to the coast contribute to a low concentration and quick dispersion of pollutants.

For Soledad, the team calculated the average PM2.5 concentration for all the trip routes measured. In contrast with Puerto Viejo, during weekday rush hours in the mornings and afternoons, and weekend values (Figure 10) are higher than the 2021 recommended values of the World Health Organization

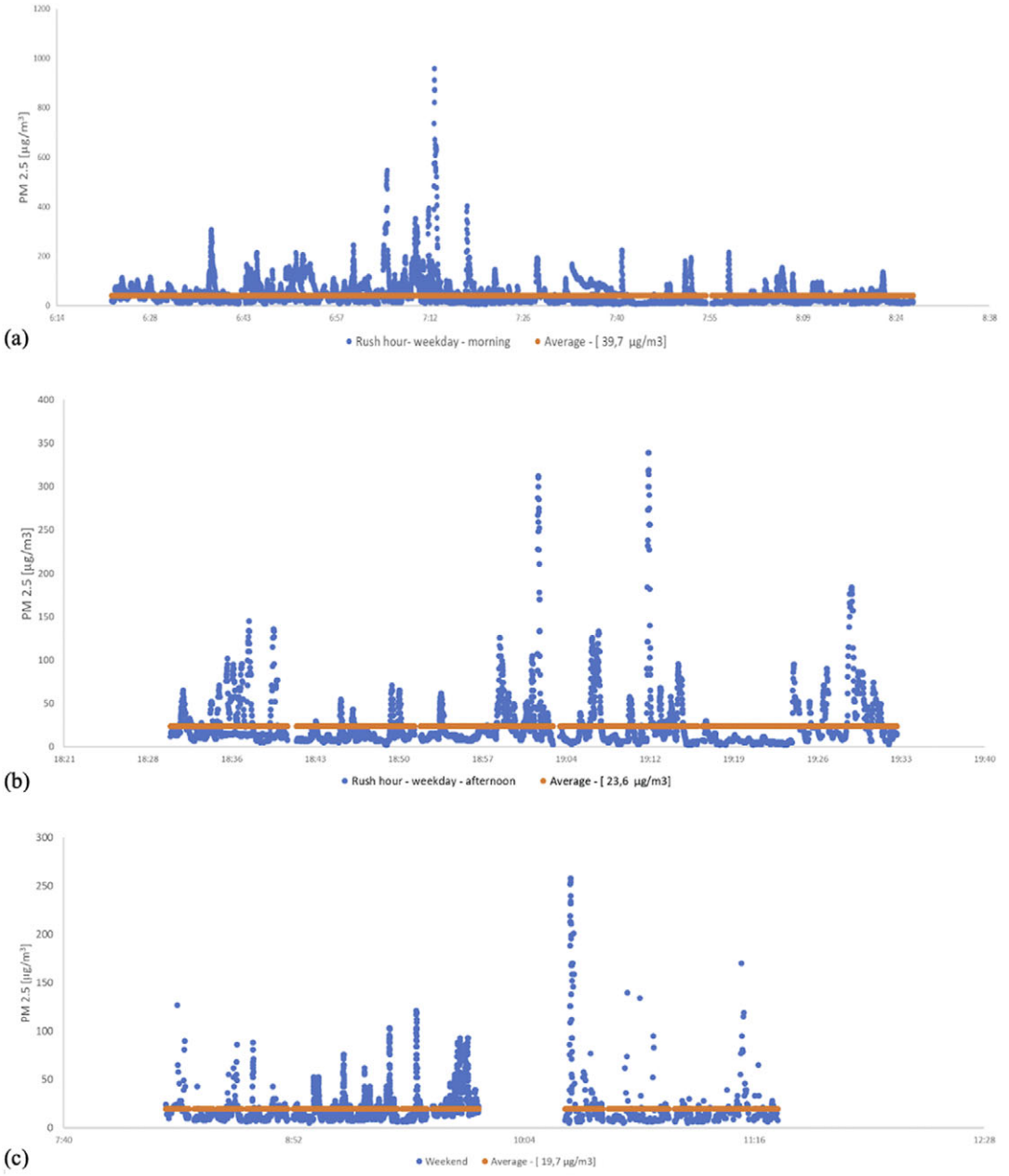

Figure 10. *Measurement of PM2.5 in MTW trips in Soledad.*

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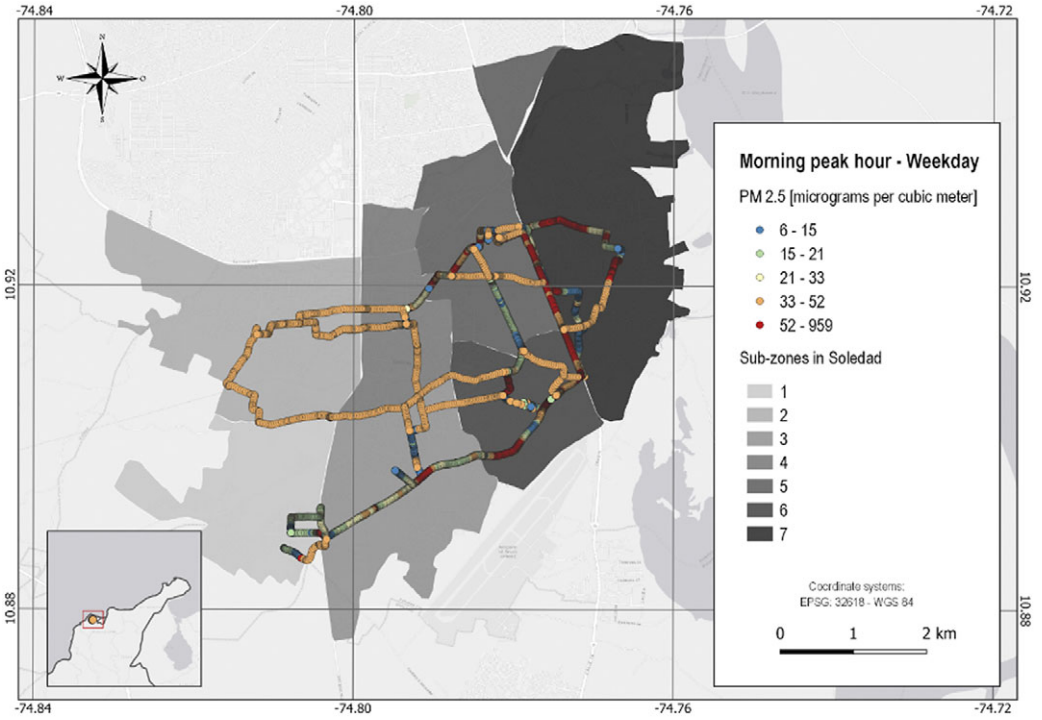

Figure 11. *Spatial distribution of PM2.5 concentrations in the road network assessed in the morning peak.*

(15 μg m^{-3}) and the Colombian government (37 μg m^{-3}). Significant location differences exist, with the highest values obtained during traffic congestion. Results evidenced high PM2.5 levels (average 39.7, 23.6, and 19.7 μg m^{-3}), with the highest value of 959 μg m^{-3} in the morning peak. Lower concentrations were obtained on weekends, demonstrating the traffic influence in PM2.5 personal exposure. The location also influences the pollution patterns (Figure 11) that are not uniform throughout the territory; concentration peaks (red color) are recorded in locations with high vehicular flow and traffic light stops. For the morning peak period, the 77.8% of km traveled within the sample design exceeded the permissible limits established by local and international regulations for PM2.5, 37 μg/m^3 and 15 μg/m^3, respectively. Similarly, lower pollution magnitudes are observed for the weekend compared to the morning peak, with 63.2% of km traveled within the sample design exceeding the permissible limits.

The substantial differences between the two case studies as well as the variation in the measurements in Soledad dependent on other sources of pollution, point to the small contribution of MTW to air pollution.

6.2.2. GHG emission estimates

An analysis of 38 license plates obtained from the site visit to Puerto Viejo and a database containing a list of vehicles and drivers provided by one of the operators in the area found three main types of vehicle models operating in the area: Bajaj RE 4S (79% of all the sampled vehicles), Piaggio Ape City (16% of all the sampled vehicles), and TVS King Deluxe (5% of all the sampled vehicles). All MTW found in Puerto Viejo use four-stroke engines (two-stroke engines are illegal in Costa Rica) and use gasoline. Most vehicle models range between 2018 and 2019, the average model being 2019 (Figure 12). The three existing regulated taxis in the area are a 2006 Peugeot Partner (diesel fuel), a 2010 Daihatsu Terios (gasoline fuel), and a 2009 Mitsubishi L200 (diesel fuel).

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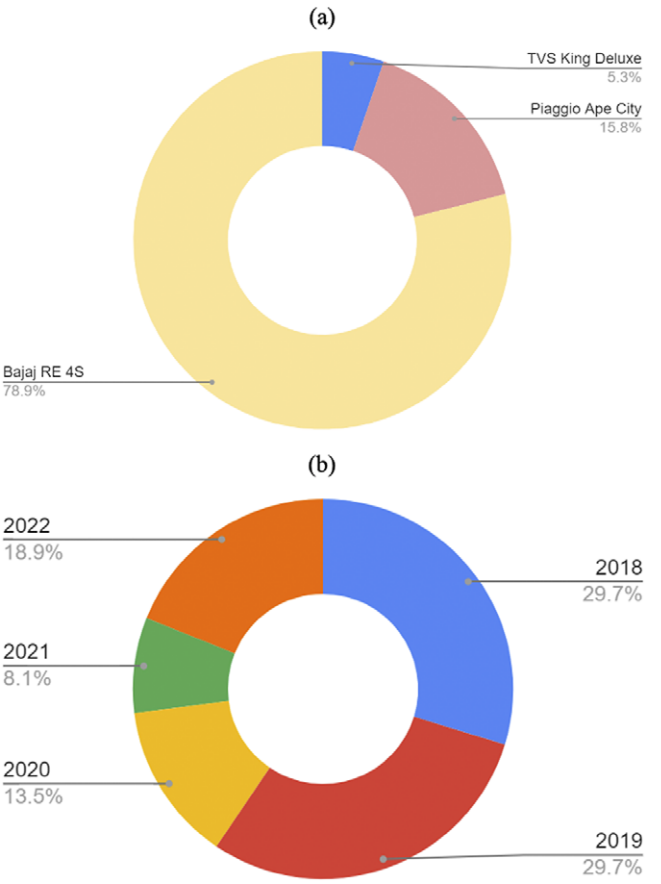

Figure 12. *Distribution of MTW vehicle models and ages in Puerto Viejo.*

Based on the data, the Bajaj RE 4S was used as the default vehicle type for estimating GHG emissions. For Puerto Viejo, the emissions for the total of km that each MTW travels per working day are 9.54 kg CO_2 eq. Our calculations showed that if these trips were made with the taxis available in the area, the total emissions would more than double, resulting in 19.2 kg CO_2 eq. In a more optimistic scenario, if all these trips were made using Toyota Yaris 2022 sedan vehicles to substitute MTW, the total emissions per vehicle in a working day would be 15.2 kg CO_2 eq, 55% higher than the emissions from the existing MTW. Because Puerto Viejo and its surrounding area is semi-rural and has many gravel roads, this scenario is unrealistic but valuable, considering sedans are the most common vehicle used for cabs in Costa Rica. The comparison with taxis and not with nonmotorized options such as bicycles or pedestrians responds to the similarity of use of the two modes. The weather conditions of Puerto Viejo—average temperature is X—make nonmotorized modes more strenuous and less likely to be a substitute for motorized modes (Table 3).

In Soledad, based on the average distance traveled (Figure 13) and the vehicle efficiency for each vehicle type (Table 4). The GHG estimation for Soledad showed that emissions for the total km traveled by MTW vehicles are 7940.15 kg CO_2 eq/day, reaching 2860 Ton CO_2 eq/year. These calculations show that 1.72% of the emissions generated by the vehicle fleet are present in the study area. If these same trips were made by other modes such as motorcycles or cars, emissions would reach 17% and 21% of the emissions generated by the entire vehicular flow.

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Table 3. *Comparative GHG emissions per vehicle per year according to different vehicle typology*

Category	Performance (gal/ Km)	Activity factor (VEH-KM/year)	Emission factor (kg CO_2 eq/gal)	Emission (kg CO_2 eq/year)	Emission (Ton CO_2 eq/year)
Car	0.01	324,930,370	8.15	34,978,783.54	34,978.78
Bus (C2)	0.08	64,840,772	10.15	54,844,486.73	54,844.49
C2L	0.03	19,434,069	10.15	6,686,637.323	6,686.64
C2G	0.09	21,886,031	10.15	19,316,801.32	19,316.8
C3S2	0.18	2,361,149	10.15	4,357,392.376	4,357.39
C4	0.18	635,694	10.15	1,173,144.101	1,173.14
C5	0.18	7,355,886	10.15	13,574,953.17	13,574.95
Motorcycle	0.01	344,455,252	8.15	28,073,103.05	28,073.1
Motorized three-wheelers	0.01	31,884,587	8.15	2,860,315.563	2,860.32

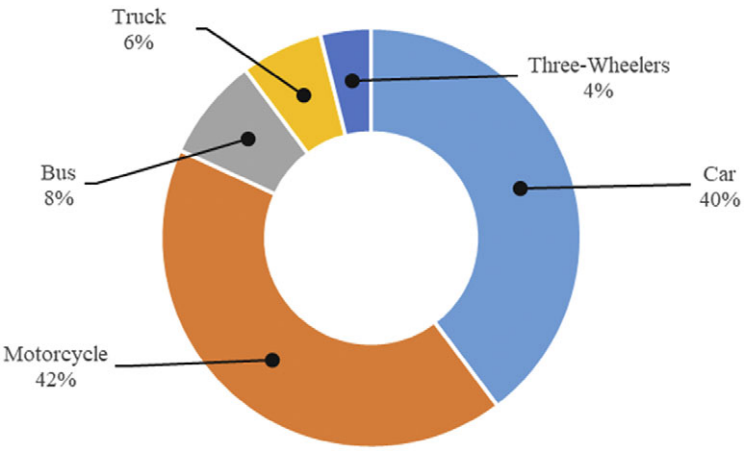

Figure 13. *Distribution of distance traveled by each vehicle category in Soledad.*

Table 4. *Comparative GHG emissions per vehicle per year according to different vehicle typology*

Category	Performance (gal/ km)	Activity factor (VEH-KM/year)	Emission factor (kg CO_2 eq/gal)	Emission (kg CO_2 eq/year)	Emission (Ton CO_2 eq/year)
Car	0.01	324,930,370	8.15	34,978,783.54	34,978.78
Bus (C2)	0.08	64,840,772	10.15	54,844,486.73	54,844.49
C2L	0.03	19,434,069	10.15	6,686,637.323	6,686.64
C2G	0.09	21,886,031	10.15	19,316,801.32	19,316.80
C3S2	0.18	2,361,149	10.15	4,357,392.376	4,357.39
C4	0.18	635,694	10.15	1,173,144.101	1,173.14
C5	0.18	7,355,886	10.15	13,574,953.17	13,574.95
Motorcycle	0.01	344,455,252	8.15	28,073,103.05	28,073.10
Motorized three-wheelers	0.01	31,884,587	8.15	2,860,315.563	2,860.32

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7. Discussion: On the Influence of MTW on the Inaccessibility-Social Exclusion Cycle

MTW are the third main mode of travel in Puerto Viejo and Soledad (albeit within markedly different timeframes). This is a significant finding considering our two case studies' differences in scale and urban configurations. On the one hand, Puerto Viejo illustrates an instance of rapid consolidation of a relevant transport market share, despite the relatively recent introduction of these vehicles. On the other hand, and despite a more diverse ecosystem for collective transport in Soledad, the data suggest these vehicles have filled a relevant gap in transport supply.

Against this backdrop, it is possible to infer that MTWs address previously unmet mobility needs by the existing transport system in our two selected empirical contexts. In this vein, they can potentially disrupt the fragmentation cycle in transport networks and the inaccessibility and social exclusion that can emerge from such fragmentation, as conceptualized in Section 3. Such a potential is more evident in the contributions of motorized three-wheelers to accessibility to livelihoods, recreation, and care activities. Less clear is their contribution to accessibility to education. These services also have diverse effects over some of the most salient dimensions of social exclusion. These contributions are unpacked and discussed in detail below.

7.1. Increasing geographical access

MTW fit within gaps produced by the specific trajectories of the development of transport systems in Puerto Viejo and Soledad, playing a role in supplying transport at different scales of operation and spatial coverage. The flexibility in the operation of these services has enabled them to adapt to changing supply conditions over time. Different strategies were identified for adapting to the changing geographies of transport supply: to establish hubs or service areas or corridors that respond to the functional configuration of the urban spaces in which they operate, and which find synergies with existing land uses and terminals for other transport services for increasing demand. This is consistent with research both within and outside Latin America and the Caribbean.

Considering the more rigid schedules and operation patterns of competing transport services in both contexts, MTWs also fill temporal gaps in transport and account for the diversity of users meeting their needs at "unusual" hours for the local context. As such, MTWs address some of the localized complexities of the temporal dimension of accessibility, albeit at a premium, potentially pricing out poorer users when they may need access to public transport the most.

7.2. Reducing exclusion from facilities

The use patterns of MTWs are closely linked with their ability to provide access to different opportunities in each context. The distribution and functioning of facilities where different activities can be completed refer to the land-use component of accessibility and the individual characteristics of those seeking to carry out such activities. In both cases, centralization of facilities and well-defined infrastructure corridors predetermine what neighborhoods are more accessible.

Similarly, how well MTWs adapt and respond to these configurations determines their contributions to access relevant social inclusion opportunities. MTWs are instrumental in securing access to employment in both case studies, particularly for groups often excluded from conventional public transport, such as shift and night-time workers. This is consistent with the literature on social exclusion in the LAC context, which suggests that popular transport plays a fundamental role in securing access to income above other opportunities. Interestingly, the evidence does not suggest that MTWs play a similar role in enabling access to education. A limitation of this study is the lack of evidence from minors due to ethical concerns. This warrants further investigation as available data in this segment is scarce.

The analysis of the selected contexts shows the relevance of different driving local economies. In the Puerto Viejo area, MTW' role in ensuring connectivity and access to mobility for touristic activities and sites has become essential. Their relevance for safely and easily accessing recreational activities in both cities at night should also be considered. The interruption of these services can result in economic impacts

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for residents, local businesses, drivers, and tourists, in addition to the exclusion of certain populations without access to a motorized vehicle to access these types of activities. Furthermore, evidence about travel for leisure in both cases shows that MTWs in Soledad serve a more disadvantaged population than they do in Puerto Viejo. This, however, does not reduce the relevance of these services for vulnerable populations, who reported using them for social interactions and accessing open green spaces. Enabling coverage of traditional services and their availability in accessible and affordable spaces for leisure, recreation, and sports may go a long way in improving the accessibility of low-income residents to these opportunities.

While the evidence about care mobilities is limited, errands were identified as a relevant travel purpose being addressed by MTWs in both cases. This is consistent with findings emerging from the analysis of the geographic dimension of social exclusion that highlighted the flexibility of these services to respond to needs addressed with diverse locations and times. MTWs hold significant potential for improving access to care facilities such as hospitals, particularly when transport supply is scarce. However, they require support, and integration with these facilities, which is currently absent in the two case studies.

7.3. Changing the affordability of transport

Fares and their integration are significant drivers of (in)accessibility and can constitute a barrier to inclusion. As such, MTWs adapt to current fare schemes for individual and collective transport in both cases, being influenced differently by regulations, involving imbalances in power, and mediating relationships between suppliers and users that ultimately enable or restrict access to specific opportunities. Given the informal nature of MTWs, the relationships between service providers and users are often unequal, opening room for irregular fares and excessive premiums on services in areas or times with limited or no coverage of alternative transportation. This is the dimension of social exclusion where MTW are less likely to make positive contributions. Lack of fare control and enforceable pricing standards restrict the increase of fares for vulnerable populations. Nonetheless, the literature has pointed to the potential of popular transport for building social capital between users and providers, enabling better affordability for users with limited purchasing power or in conditions of social vulnerability.

7.4. Reducing fear of crime, injury, and harassment

Pockets of exclusion tend to be pockets of insecurity, and MTWs respond differently to the spatial distribution of crime and the enabling conditions of other drivers of fear, such as perceptions of insecurity, fear of injury, and sexual harassment. In line with research about subjective perceptions of transport systems, safety and security are often governed by the public's image of other transport modes and public space. Stigma associated with crime and violence can linger in the collective conscience, changing perceptions about transport modes, and often leading some social groups to avoid them altogether. Despite this, the relationship between perceived insecurity in MTWs is at odds with the perceived insecurity at specific times of the day or in parts of the city.

Filtered by gender, the experience is distributed in the same quarters. The difference in perceptions between men and women regarding safety was similar to the one found for comfort.

The lack of involvement of authorities, beyond attempts to fine or confiscate MTW, is perpetuating the inequalities and vulnerabilities of drivers and users regarding job precarity, affordability, and safety of these services. Measures intended to improve the safety of MTW users must not unintentionally result in increasing other types of risks. Any policies aiming to tackle insecurity in the sector must be accompanied by an integrated approach to safety and mobility and ensure that people are not left without options to move in a safe and efficient way.

7.5. Addressing the needs of the vulnerable

Beyond stigma, fear, and safety concerns regarding these services, women continue to use them and are the majority users of MTW in both case studies. This implies a need to use these services even if they do

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not constitute the ideal user experience for this population. Improving the safety and experience of using MTWs will be key to reducing the vulnerability of these users. In Soledad, a third of the disabled respondents are MTW users.

Although operators suggest that they provide services for a wide diversity of users, further research is recommended to determine whether these services are actually improving transport access to these specific populations.

7.6. Environmental impacts and externalities

The urban configuration, mobility system, and city typology in each case study generated very different results in terms of air pollution between Soledad and Puerto Viejo. Puerto Viejo's low-density urban configuration, with small-scale coastal developments, high presence of natural landscapes, and a small-scale vehicle fleet, and road network has maintained good air quality levels. On the other hand, Soledad's larger urban scale, density, and vehicular dynamics have affected air quality levels and increased exposure to drivers and passengers as well.

Regarding GHG emissions, both cities showed that the use of MTW contributes to lower emissions mobility. If MTW trips were substituted by trips with other existing transport modes (including motorcycles), emissions would increase significantly. Regulatory efforts to ban these types of services reduce mobility options for users and go against transport decarbonization goals.

Although MTW vehicles contribute less to the CO_2 eq emissions in the study areas, particularly in Soledad, they are exposed to high pollution levels from other vehicles, adding vulnerability to drivers.

7.7. The positive and negative effects of MTW on accessibility and social exclusion

In this section, we engaged in an in-depth analysis of the influence exerted by MTW on the cycle of inaccessibility and social exclusion. We observed that MTW constitute the third principal mode of travel in Puerto Viejo and Soledad, albeit operating within distinct temporal frameworks. This revelation holds considerable significance, especially when juxtaposed against the backdrop of the dissimilar scales and urban configurations characterizing our two selected case studies.

Exploring MTW' influence on the inaccessibility-social exclusion cycle unveils a multifaceted spectrum of positive and negative impacts. While MTWs address critical gaps in geographical access, contribute to employment and care mobility, and offer lower emissions mobility, they also exhibit shortcomings in affordability, safety, and potential environmental consequences. Regarding affordability, the irregular fare structures and varying premiums of MTWs can result in irregular pricing, potentially excluding economically vulnerable individuals. Additionally, the uneven perception of safety associated with MTWs, particularly among women, highlights areas where further improvements are needed to alleviate concerns. Moreover, MTWs may contribute to congestion and air quality issues in denser urban areas like Soledad, adversely impacting the overall urban environment. Acknowledging these nuanced dynamics is vital for informing policy decisions that harness the positive attributes of MTWs while mitigating their negative repercussions.

8. Conclusions

This research presented an overview of the functioning and social and environmental contributions of MTWs in two distinct Caribbean cities. The paper laid out evidence from various sources collected through low-cost methodologies for improving the understanding of MTW transport services in Puerto Viejo and Soledad that can be replicated in other cities in LAC. Beyond comparing the two case studies, carrying out research on urban settings with a very different scales, availability of information, urban configuration, and urban dynamics allowed us to gather insights into the contributions of MTWs in different urban realities, setting the foundations for potential comparisons with similar cases explored by other authors.

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We set out from a photograph of the cities at the time of the research, recognizing that they have followed different development trajectories and pathways to consolidate their respective transport systems. However, for future research, it becomes necessary to understand how these vehicles influence the urban trajectory in the long term, as they may contribute to changes in the different determinants of accessibility and their implications for social exclusion.

There has been no previous research on the issues covered by this study in Puerto Viejo, and there is nascent research in the context of Barranquilla and Soledad. Therefore, the methodological challenges in each case are different, and they require unique approaches to the collection of information and their interpretation. In Puerto Viejo, an initial wave of remote data collection was necessary to establish the partnerships and rapport necessary for collecting data on-site. Challenges with access to the site and limited localized capacity for long-term data collection constrained the scale of evidence obtained. Further research would benefit from a larger and more targeted sample that can capture the unique needs and perceptions of vulnerable groups such as lower-income households and indigenous and Afro-descendant populations. Such an exercise can be complemented by traffic counts that can help understand better the road ecosystems in which MTWs operate.

Using low-cost sensors proved a valuable exercise that enables efficient data collection for distributional analysis. The findings obtained in this study are but an exploration of the environmental justice implications of MTWs. To further our current understanding of the environmental impacts of MTWs, it is necessary to introduce additional waves of data collection that can capture measurements in different seasons (dry vs. rainy) to identify variations in air quality levels and exposure of drivers, users, and third parties to pollutants. Furthermore, considering this exercise establishes links and partnerships in both cases with MTW drivers, further research could leverage these to involve a more precise GHG estimation using real-time data on distance traveled (using GPS), tachometer readings, or fuel consumption records.

Insights from our research can serve as the basis for participatory processes seeking to chart a roadmap for regulating and supporting MTW drivers within a formal regulatory framework. Such a framework, underpinned by principles of justice and inclusion, should aim at reducing the existing vulnerabilities of drivers and other actors in the MTW' business, while improving the safety, quality, and operation to maximize their positive social and environmental contributions.

In both cases, but perhaps more so in Puerto Viejo, visibility is instrumental in initiating positive change and placing MTWs as a legitimate part of the transport systems in both cities. Our research is a step forward in producing reliable knowledge that can inform further debates on the role of these transport modes from a social and environmental perspective. Different outcomes can be further explored in this and similar cities. These include impacts on connectivity and access to jobs, services, and recreation, and the targeted analysis of areas historically excluded from investments, opportunities, and quality public transport services.

While many findings and insights from the analysis hold potential for local advocacy and informing policymaking, findings can also serve as a first step in the consolidation of an already growing research agenda on popular—rather than informal—transport in the region. Such a change requires a more precise understanding of the structural drivers of local economies and urban development trends that allow researchers and practitioners to better contextualize their analysis of transport modes and their impacts on diverse populations with intersecting identities, priorities, needs, and preferences.

Data availability statement. The data that support the findings of this study are openly available in TUMI Data Hub at https://hub.tumidata.org/.

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supervision: M.N.-C., A.S.G., D.A.; investigation: M.N.-C., A.S.G., A.Q., D.A.; writing: M.N.-C.; writing – original draft: A.S.G., D.O.; writing – review & editing: D.O.; project administration: A.S.G., D.A.; visualization: A.Q.

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Competing interest. The authors declare no competing interests exist.

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Appendix

Table 1. *Census percent distribution of sociodemographic characteristics*

Gender	Age	Ethnicity	Place of birth	Disability	Strata	% National Census	% Surveys
						100.00%	
woman	20-24 years	no ethnic group	born in another municipality	without disability	E1	2.10%	2.20%
woman	25-29 years	no ethnic group	born in another municipality	without disability	E1	2.10%	2.20%
man	20-24 years	no ethnic group	born in another municipality	without disability	E1	2%	2%
man	25-29 years	no ethnic group	born in another municipality	without disability	E1	1.90%	2%
man	15-19 years	no ethnic group	born in another municipality	without disability	E1	1.90%	2%
woman	15-19 years	no ethnic group	born in another municipality	without disability	E1	1.90%	2%
woman	30-34 years	no ethnic group	born in another municipality	without disability	E1	1.80%	2%
man	30-34 years	no ethnic group	born in another municipality	without disability	E1	1.80%	1.80%
woman	35-39 years	no ethnic group	born in another municipality	without disability	E1	1.80%	1.80%
woman	25-29 years	no ethnic group	born in another municipality	without disability	E2	1.70%	1.80%
woman	20-24 years	no ethnic group	born in another municipality	without disability	E2	1.70%	1.80%

Table 2. *Relation Housing and Population Census 2018 (DANE, 2018) to survey's final sample*

Characteristics	National census (%)	Survey data (%)
Gender identity		
Man	48.70%	51.80%
Woman	51.30%	48.10%
Trans	0.00%	0.20%
Age (years)		
20-30	43.94%	36.96%
31-43	24.28%	25.29%
44-56	19.27%	23.15%
57-69	8.61%	11.87%
70-82	2.67%	2.72%
83-100	0.57%	0.00%
Ethnicity		
Indígena	0.08%	1.95%
Gitano(a) o Rrom	0.00%	0%
Raizal	0.01%	0.19%
Palenquero(a) de San Basilio	0.02%	0%
Negro(a), Mulato(a), Afrodescendiente	1.30%	11.48%
Ningún grupo étnico	98.58%	86.38%
Place of birth		
In this municipality	15.45%	29.25%
In another Colombian municipality	72.29%	66.60%
In another country	8.26%	4.15%
Prefer not to respond	4.00%	0%
Disability		
Yes	3.36%	3.70%
No	96.64%	96.11%
Prefer not to respond	0%	0.19%
Strata		
1	37.65%	55.25%
2	56.67%	42.80%
3	5.21%	1.95%
4	0.12%	0.00%
5	0.04%	0.00%
6	0.02%	0.00%
Prefer not to respond	0.29%	0.00%

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Table 3. *Data sources and observations used for the estimation of GHG emissions from a working day of a motorised three-wheeler driver in Puerto Viejo.*

Data	Units	Source	Observations
Average distance travelled in a workday or shift	km	Data collected from a three-wheeler driver and owner of the Tuk Tuk Central (I5).	This distance is an average based on the trips made in a workday. It was verified with the O-D data collected in this work, according to the average km travelled in a trip and the number of trips made in a day.
Vehicle fuel efficiency (three-wheelers)	km/L	Torito 205 Bajaj user's manual (2022)	Efficiency of the Bajaj RE 4S, the most used motorised three-wheeler in Puerto Viejo. The average age of three-wheelers in Puerto Viejo is 2019, however no specifications were found for older models
Vehicle fuel efficiency (taxis)	km/L	Auto-Data (2020) for the performance of the model of each taxi. Herández, L (Diario As) (2022) for the Toyota Yaris.	Depending on the model of the vehicle, its theoretical performance was consulted on the internet. Taxis available in Puerto Viejo are a 2006 Peugeot Partner, a 2011 Daihatsu Terios and a 2009 Mitsubishi L200. In the case of sedan vehicle scenarios, a Toyota Yaris 2022 was taken into account. When calculating taxi emissions it is assumed that the totality uses diesel to be conservative with the calculation since ⅔ taxi vehicles are diesel-powered.
CO_2 emission factor	CO_2 kg / L of fuel	National Meteorological Institute (IMN) (2022)	The IMN reports an emission factor depending on whether the vehicle uses gasoline or diesel. The corresponding value is used according to the fuel used by the vehicle.
CH_4 emission factor/ without catalyst	kg CH_4 /L of fuel	National Meteorological Institute (IMN) (2022)	The IMN reports an emission factor depending on whether the vehicle uses gasoline or diesel. The corresponding value is used according to the fuel used by the vehicle.
N_2O emission factor/ without catalyst	kg N_2O /L of fuel	National Meteorological Institute (IMN) (2022)	The IMN reports an emission factor depending on whether the vehicle uses gasoline or diesel. The corresponding value is used according to the fuel used by the vehicle.
Global warming potential	-	National Meteorological Institute (IMN) (2022)	100-year time horizon

Table 4. *Summary of bus services and hours for the Puerto Viejo area in Costa Rica*

Hour	Route					
	700 - San José – Cahuita – Puerto Viejo – Manzanillo		725 - Limón – Cahuita – Puerto Viejo - Manzanillo		725 - Puerto Viejo – Bribri - Sixaola	
	SJ-MZ	MZ-SJ	L-MZ	MZ-L	PV-SX	SX-PV
1						
2						
3						
4				1		
5				1	1	
6			1	1	1	
7				1	1	1
8				1		
9				1		1
10				1	1	
11				1		1
12		1		1	1	
13				1		1
14				1	1	
15				1		1
16				1	1	
17				1		1
18				1	1	1
19						
20						
21						
22						
23						
24						

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