Arguments for cycling as a mechanism for sustainable modal shifts in Bogotá

Abstract

As a clean, accessible and healthy transport alternative, the benefits of cycling have been well-documented and suggest positive health, environmental and affordability outcomes. Despite a favourable rhetoric for cycling, in many cities in Latin America, its uptake has gained more traction among younger and carless populations than frequent users of private motorised vehicles. Recognising this reality, our article poses arguments for cycling beyond its classic benefits via direct comparisons of its performance against that of private cars. Our paper compares cycling and car-based trips, presenting evidence in cycling for policy and decision-making targeting a demand segment that has historically been more resistant to modal shifts to sustainable mobility. We contrast performance of both modes in relation to coverage and accessibility, testing different modal shift scenarios in the context of Bogotá, Colombia's capital city. As a city that has been recognised in the international literature for both its successes in urban transport policy and its persisting mobility and access inequalities, Bogotá's contrasts are an ideal setting for this research. We build on a geo-coded household travel survey for 2015 and API-sourced datasets to develop spatial coverage and potential accessibility metrics for cycling and car-based trips. Findings suggest Bogotá's large potential for further increases in cycling, particularly from car-users, which can lead to overall societal gains in terms of sustainable accessibility and present a fertile ground for bike-sharing systems. The paper builds on spatially and socially distributed findings to identify areas with the highest potential for bike-sharing in Bogotá.

Keywords: Cycling, Bogotá, accessibility, modal shift, Bike-sharing

1. Introduction

Agenda 2030's Sustainable Development Goals and the implementation of UN-Habitat's New Urban Agenda have highlighted cycling as an instrumental form or urban mobility (Hackl, 2018). Cycling has gained recognition as an essential sustainable transport alternative amid unprecedented climate change and health crises (Pucher and Buehler, 2017). Its various determinants and positive social, economic and environmental benefits for cities have been well-documented in different scales and contexts (Buehler and Dill, 2016; Clark and Curl, 2016; Heinen et al., 2010; Pucher and Buehler, 2008). Such an interest in cycling from research has been accompanied by a growing focus on development of pro-bicycle policies and infrastructure from practitioners at all levels. As millions opt out of public transport in the wake of the COVID-19 pandemic, non-motorised transport will play an ever-growing role in enabling low-carbon access to critical goods and services, protecting livelihoods, and strengthening local access.

This article explores arguments in favour of cycling in Bogotá, emphasising on its potential for enticing shifts from car-based trips and exploring avenues to maximise short-term gains that can serve as the bedrock for more progressive and sustainable urban mobility transitions. The paper's premise is a simple one: the bicycle outperforms the private car under most circumstances in which current car-based trips are made in Bogotá, but modal shifts can only be made possible by policies seeking to maximise access to cycling and its positive efficiency, social, and environmental effects. The paper approaches bike-sharing schemes as a feasible policy alternative with the capacity to increase access to the bicycle and maximise its potential in the short term. Our premise is tested by confronting current car-based trips vis-à-vis their hypothetical cycling trip equivalents in a variety of scenarios. Building on the notion of accessibility, understood as "the potential of opportunities for interaction" (Hansen, 1959), the paper estimates the accessibility benefits of different levels of substitution of car drivers by bicycle users. We compare travel times and distances by private vehicle trips to critically assess their coverage and efficiency. The paper tests different scenarios of mode substitution using an accessibility model that estimates their effects on access to employment, detailing accessibility variations under different scenarios.

The paper's methodology proposes relevant criteria to identify the areas of the city with the highest potential for implementing bike-sharing as a tool to facilitate a modal shift from the private car. The focus on these two modes in a context such as Bogotá departs from the recognition that a large share of current research and policy development in the city has focused on public transit and its associated inequalities, without much emphasis on car-oriented groups of the population. Building on the notion of accessibility, the paper prioritises areas where the initial implementation of bike-sharing systems can lead to short-term gains in accessibility, sustainability, and efficiency by positioning the bicycle as an attractive alternative to the private vehicle. The proposed approach recognises the inevitable trade-offs involved in simultaneously pursuing environmental, social and economic objectives in public policy (Rydin, 2013). Considering the already long trajectory of development of cycling infrastructure and policies to support bicycle uptake in Bogotá, we seek to leverage higher short-term sustainability and accessibility benefits to support long-term scaling-up of bike-sharing implementation. Such a strategy, may not only support the early success of bike-sharing pilots in the city, but also secure sufficient demand so public resources can be targeted to extend bike-sharing to areas historically bypassed by transport investments (Oviedo Hernandez and Dávila, 2016).

A long line of research suggests that Bogotá has more considerable potential for cycling than what is currently accounted for. Such potential can produce benefits ranging from travel time savings to improvements in health, economy, and accessibility. Recognising and providing evidence on such potential is a practical starting point for discussing and analysing new policy interventions and infrastructure investments that support cycling uptake in the medium and long term. Materialising and taking advantage of Bogota's potential for cycling, particularly in the context of the COVID-19 pandemic and the outcomes resulting from associated lockdown measures, implies exploring mechanisms for developing bike-sharing to sort the complex political, social and economic barriers this type of urban projects typically face (Duran-Rodas et al., 2020; Mora and Moran, 2020). By promoting bike-sharing policies that sway users away from the private vehicle, it is possible to pave the way for large-scale implementation in the medium and long-term.

2. Literature review: Bike-sharing as a potential mechanism to leverage transitions to the bicycle

Research has not focused on the specificities of how cycling can compete with cars and the potential of bike-sharing to offer faster trips and to improve accessibility. In one of the few works focusing on bike-sharing as an alternative to motorised transport, Faghih-Imani et al. (2017) compared taxis and the bike-sharing system of New York City using travel time differences. This research found that the bike-sharing system is often faster than taxis, offering a competitive alternative for able-bodied populations.

Bike-sharing can contribute to reducing negative externalities of urban development models favouring car-centred mobilities. When directly compared with private motorised vehicles, namely cars and motorcycles, the bicycle has been recognised to have a lower carbon footprint and to be more efficient in its use of the road and public spaces (Larsen et al., 2013). Bicycles can also provide further health benefits than their motorised competitors (see Woodcock et al., 2014). Under suitable operation conditions, their use reduces the risks of injuries and fatalities (Fishman and Schepers, 2016). Moreover, both private cycling and bike-sharing can ease economic burdens of travel because of significantly low ownership and operation costs, especially when compared to those of private cars and motorbikes.

Despite the many advertised benefits of cycling and bikeshare systems, some authors have argued that bikeshare systems are often adopted because governments want to showcase them as symbols of sophistication and not because bikeshare systems are understood as a transport tool (Médard de Chardon et al., 2017). The implication being that investments are done without really understanding what has worked in the past and what could work in the future. For example, recent research has challenged the idea that more stations and number of bicycles improve bikeshare systems' performance (measured as trips per day per bike -TDB-) (Médard de Chardon et al., 2017). Moreover, the same research suggests that temperature, wind, and non-profit operation could reduce TDB.

From a social perspective, a relevant concern regarding bike-sharing systems is their ability to serve transport-disadvantaged communities and tackle transport-driven inequalities (Médard de Chardon, 2019). As a frequent private venture, bike-sharing systems often focus on profitability, serving first high-demand areas and population segments with higher purchasing power at the expense of leaving out people who might already be excluded (Deka, 2018; Qian and Niemeier, 2019). Research in Chicago and Philadelphia shows that an efficient bike-sharing system can improve accessibility in disadvantaged communities to the same or even to a more considerable extent it would for other populations (Qian and Niemeier, 2019). Moreover, locating stations near disadvantaged communities could increase access to employment and services. Work by Bachand-marleau et al., (2012) found that people living near bike-sharing stations in Montreal are 3.2 times more likely to use the system, with research suggesting that financial savings in low-income neighbourhoods and closeness to stations are explanatory variables of cycling ridership (Fishman, 2016).

Another recent concern is the problem associated with constantly rebalancing bikeshare systems in order to ensure an optimal operation. A study reviewing the operation of bikeshare systems nine cities in Europe and the United States (Médard de Chardon et al., 2016) found that operators are constrained by contested goals such as utility or maximizing trips. Furthermore, bike-share stations near transit stations are being balanced the most, and balancing is often a consequence of morning and afternoon peaks.

3. Context

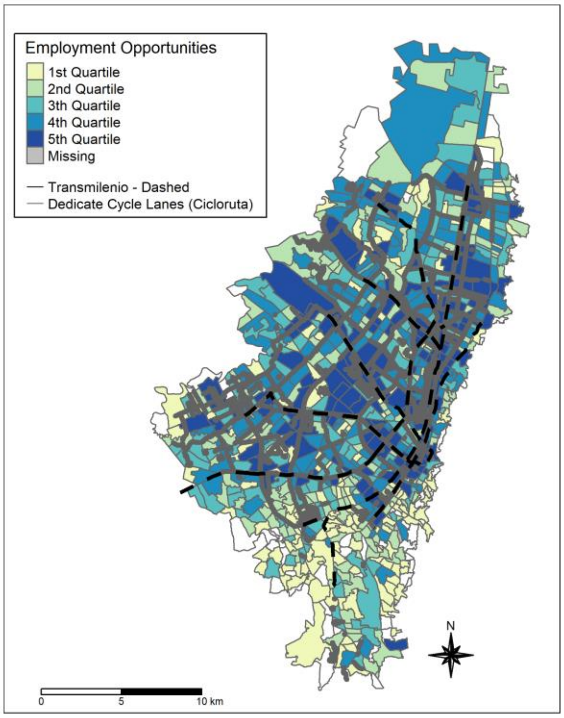
3.1. Bogotá's challenges and opportunities for cycling

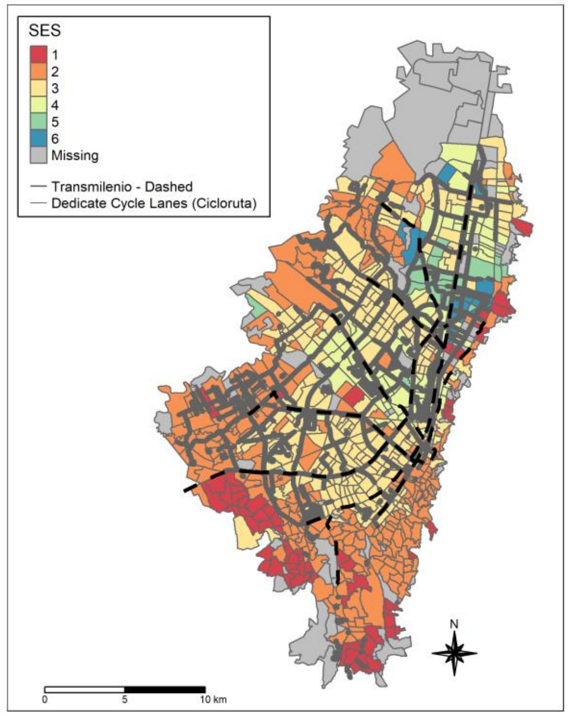
Bogotá, the capital and largest city of Colombia, has become a model of positive urban transformations and sustainable transport practices (Cervero et al., 2009). The insertion of the "ciclovia" in the 1970s started to popularise cycling among *Bogotanos* from a recreational and leisure perspective (Instituto Distrital de Recreación y Deporte - IDRD, 2020). Large-scale investments on cycling infrastructure and public space revitalisation during the 2000s and 2010s yielded the consolidation of cycling as a serious transport option. The share of cycling commuting in Bogotá and its surrounding municipalities increased from 611,343 daily trips in 2011 to 846,727 daily trips in 2015 (Secretaría Distrital de Movilidad, 2015) and by 2019, it reached 1,177,868. With over 344 km of exclusive lanes for bicycles and more than 3,000 parking spots, local administrations declared Bogotá the "World Capital of Cycling" in 2018 as a way to acknowledge historical efforts and investments to support this mode of transport (Montero, 2020). Research in the local context has identified that such network of infrastructure plays a key role in sustaining and inducing new demand for cycling commuting and fostering trips in surrounding neighbourhoods (Rodriguez-Valencia et al., 2019; Rosas-Satizábal and Rodriguez-Valencia, 2019).

Bogotá's citizenry is also active in cycling activism. This is illustrated by Castañeda (2020), who uses a perspective of playfulness in urban space to show the influence of cycling activists in strengthening access to the city by this mode. Part of the city's success in promoting cycling is explained by the combination of clearly defined policies and objectives, and a vibrant cycling culture promoted by an engaged civil society (Rosas-Satizábal and Rodriguez-Valencia, 2019). Such factors have played a vital role in the configuration of the Ciclovia as an international best practice (Montero, 2017). Moreover, Bogotá has natural conditions suitable for cycling with a mild equatorial climate and a flatter surface (Cervero et al., 2009). Today, as part of the city's strategy in response to the COVID-19 pandemic, current infrastructure has been complemented by a network of pop-up cycling lanes taking space previously reserved for private vehicles and increasing the road space for cycling and walking. Despite its many efforts, Bogotá faces large social inequalities associated with urban mobility, and it remains far from consolidating a sustainable development trajectory (Gilbert, 2015; Oviedo and Guzman, 2020a; Oviedo Hernandez and Titheridge, 2016; Teunissen et al., 2015; Torres et al., 2013). Despite the efforts to consolidate a cycling infrastructure, the city still does not have a bike-share system.

Bogotá's challenges and contradictions have an explicit spatial dimension. A socioeconomically segregated city, Bogotá concentrates most economic opportunities in the expanded city centre and near its Bus Rapid Transit network. Moreover, the highest density of cycle lanes (Ciclorutas) tends to follow a similar distribution to that of the public transport network, leading to mark differences between zones with and without access to public and non-motorized transport infrastructure (see Figure 1). Most low-income populations are concentrated in the urban peripheries, requiring travel comparatively long distances to access employment and education and other essential opportunities, and having comparatively lower access to both mass transport and cycling infrastructure compared to their wealthier counterparts (Guzman et al., 2017; Oviedo and Guzman, 2020b).

An effective means to make evident the segregation and spatial inequality observed in Bogotá is mapping socio-economic strata (SES), a local proxy to income categorised in a scale from 1 to 6 (Cantillo-García et al., 2019). In Colombia, SES is calculated by the national government considering housing condition, quality of essential services, and built environment characteristics. Figure 1 shows the predominant SES by TAZ. Previous research has also pointed at Bogotá's high population density, particularly in low-income neighbourhoods. The city also has relatively short travel distances, which can effectively accommodate cycling commuting for the majority of travel purposes (Guzman and Bocarejo, 2017; Oviedo and Guzman, 2020b; Rodriguez-Valencia et al., 2019). The population distribution of Bogotá also shows an uneven spatial distribution, with a larger share of the population living on the western side of the city (see Figure 1, bottom).


Employment Opportunities
1st Quartile
2nd Quartile
3th Quartile
4th Quartile
5th Quartile
Missing
Transmilenio - Dashed
Dedicate Cycle Lanes (Cicloruta)
N
0
5
10 km


SES
1
2
3
4
5
6
Missing
Transmilenio - Dashed
Dedicate Cycle Lanes (Cicloruta)
N
0
5
10 km

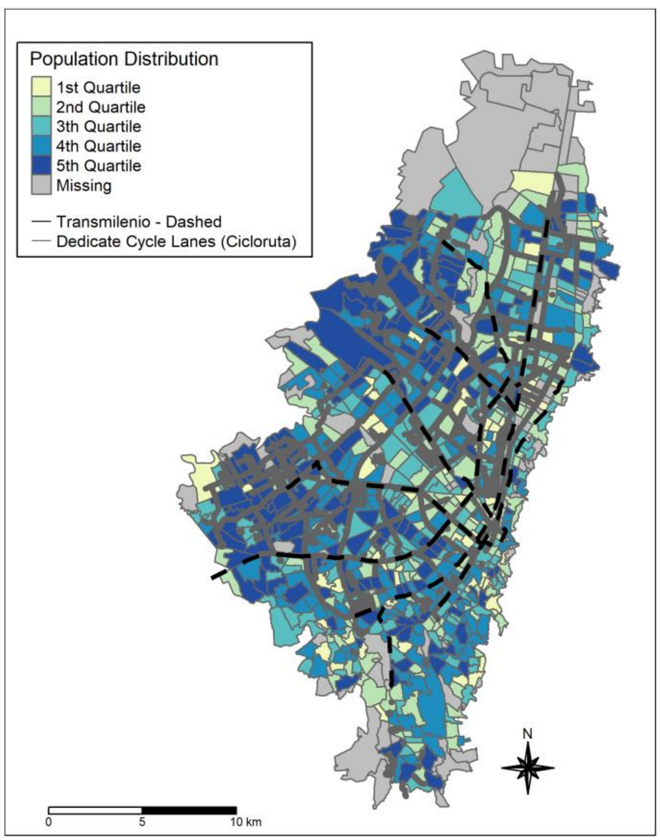

Population Distribution
1st Quartile
2nd Quartile
3th Quartile
4th Quartile
5th Quartile
Missing
Transmilenio - Dashed
Dedicate Cycle Lanes (Cicloruta)
N
0
5
10 km

Fig. 1. Employment (Top-left), spatial distribution of SES (Top-right), and population distribution in Bogotá (bottom)[1]
Source: Own Elaboration using data from Bogotá's HTS 2015

3.2. Car uptake in Bogotá

Bogotá has seen a general increase in private motorisation that puts it at a critical moment in the definition of its future development trajectory. Between 2008 and 2015, the number of private vehicles increased 1.64 times the number of cars and 3.2 times the number of motorcycles recorded in 2008 (Secretaría de Movilidad de Bogotá, 2019). Such an increase in motorisation has outpaced public authorities' capacity to cater to the increase in demand, both in terms of supply and demand management despite an overall prominence of road investments in the city's infrastructure agenda. It is therefore not surprising to find Bogotá at the top of global congestion rankings. In the INRIX ranking (INRIX, 2020), Bogotá is placed at the top as the most congested city in the world in 2019 with an average of 191 hours spent in congestion per person in a year, and with an average speed of 12 miles per hour (mph) (19.312 Km/h) and 13 mph (20.922 Km/h) for peak and non-peak hours respectively. According to INRIX, traffic speed decreases even in free-flow conditions: 27 mph (43.452 Km/h) in 2017, 25 mph (40.234 Km/h) in 2018, and 24 mph (38.624 Km/h) in 2018. In the 2019 TomTom Traffic Index (TomTom, 2019), Bogotá occupies the third place after Bengaluru (India) and Manila (Philipines), increasing congestion levels from 62% in 2017 to 63% in 2018 and 68% in 2019. As shown in Figure 2, the burden of car-based trips is also spatially concentrated, coinciding with areas with the higher-income, better-served by public transport, and in closer proximity to the main centres of employment.

Moreover, most zones with higher concentrations of car-based travel are well-served by Bogotá's network of cycle lanes. Recent research has pointed at this phenomenon, suggesting the need for targeted interventions that redistribute travel demand in a more socially and environmentally sustainable manner (Guzman et al., 2020). Out of the potential strategies that have not yet been explored in existing literature is the implementation of bike-sharing and strengthening cycling in Bogotá's urban mobility.

[1] Employment quantiles were calculated with the expanded sample of the HTS 2017. Quantiles are as follow: 19, 843, 2404, 4822, 10438, and 99489.
Population quantiles were calculated with the expanded sample of the HTS 2017. Quantiles are as follow:0, 1104, 2935, 6323 14827, and 81506.

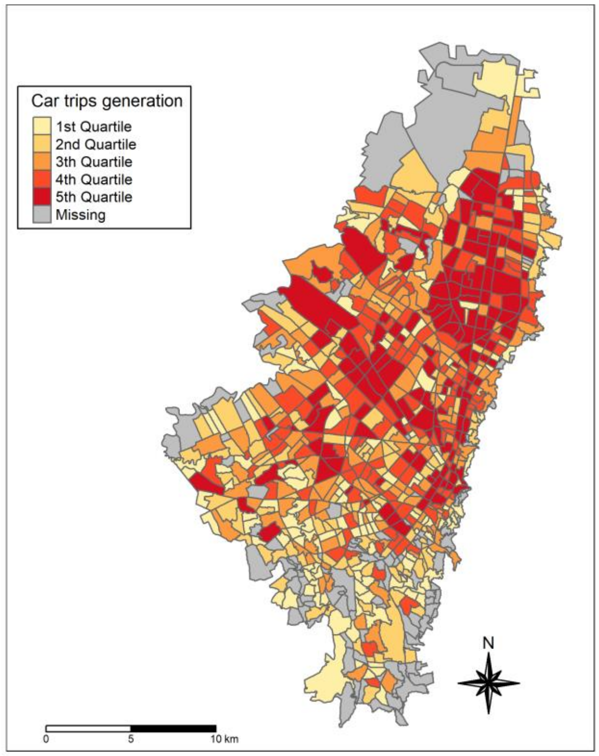


Fig. 2. Car-based trip generation in Bogotá[2]
Source: Own Elaboration using data from Bogotá's HTS (2015)

4. Data and Methods

This work is limited to Bogotá and focuses on employment trips. However, the analysis and methodology can be replicated in other cities and considering other trips should similar datasets exist. We rely on two primary data sources: the Household Travel Survey for Bogotá (HTS) (2015) and data we retrieved from the Uber Application Programming Interface API. The methodology implies simulations of work car-based trips in the HTS using the Uber API. Simulations allowed us to estimate the time and length of the trip if it was made in Uber using the departure time of the trips declared in the survey. This simulation method has yielded positive results in previous research in the same context, suggesting a promising approach for updating often unreliable datasets from travel surveys through simulations (see Oviedo et al., 2020). A requirement -met by the 2015 HTS- is that the longitude and latitude coordinates of reported trips' origins and destinations are available. Car-based trips are assigned the attributes of API-

[2] Quantiles are as follow: 3, 409, 936, 1709, 3597, 21819.

simulated journeys, and the length obtained from the Uber API is used to calculate travel times by cycling.

Once data for car-based and bicycle-based trips is consolidated, we developed a comparative analysis. Distances, travel times and potential accessibility to employment are the main metrics deployed. The first, sheds light on the geographical reach and coverage of private vehicles in Bogotá, allowing researchers to identify car-based trips made at cyclable distances. The second is a proxy for efficiency, in line with the mainstream -and often persistent- interpretations of travel choice determinants (Cervero, 2002; Gutiérrez et al., 2020). The simple matter of whether cycling can mobilise people faster than cars can give a starting indication of the number of trips that could be improved if transferred to the bicycle. Data allows us to determine its spatial and social distribution, using SES as a proxy. Finally, potential accessibility analysis by SES estimates the contribution of cycling access to employment opportunities for different population segments, going beyond the limited scope of travel features.

Despite a wealth of accessibility research in the region, the bicycle has not yet been subject to a detailed analysis of accessibility aside from the work of Pritchard et al. (2019) in the context of Brazil. The analysis of accessibility in this paper incorporates a sensitivity analysis that builds on variations in the percentage of modal shift from the car to the bicycle that uses favourable travel time as its main criterion (Pritchard et al., 2019). While the paper does not assume that travel time alone will be a sufficient justification for actual modal shifts, this analysis may support the argument that replacing car use for cycling can improve accessibility both in aggregates and for specific neighbourhoods, contributing to the reduction in transport-driven inequalities. The paper combines different analysis to identify areas with a higher potential for implementing a bike-sharing system as a mechanism to foster a sustainable modal shift.

Data processing, analysis, and visualisation were performed using the R programming language. We used the library ubeR[3] to get access to the Uber API, Tidyverse for handling and manipulating data (Lortie, 2017; Wickham, 2014), ggplot2 (Valero-Mora, 2010; Wickham, 2011) for plots, sf package (Lovelace et al., 2019; Pebesma, 2018) for geographic operations and tmap package (Tennekes, 2018) to make

[3] ubeR was archived from CRAN on 2019-02-19 and the last github commit was on 2017-05-10. When authors gathered information the library worked without problems. Uber has been updating its API and some functions in ubeR do not work properly. Yet we are confident that main issues may arise from Uber changes in the authentication protocols and for future research it is possible to recycle most of the ubeR code (https://github.com/datawookie/ubeR). Other option is to use official or unofficial community libraries (see https://developer.uber.com/docs/riders/guides/client-libraries)

the maps. All the libraries used are open software, so there are no constraints in replicating the methodology used in other contexts (with the same data availability).

4.1 Data: HTS and Uber API

Estimated Uber travel times are preferred over self-reported travel times in the HTS. The first is more precise and accounts for congestion, while the second is more likely to be influenced by respondents' biases and common issues such as rounding up time estimations. Moreover, travel distances are missing from the survey, and they are necessary for comparisons between modes. We compute hypothetical cycling travel times using the API-estimated travel routes and assuming three cycling speeds (11.5 Km/h, 13 Km/h, 14.5Km/h). The latter build on average distances observed in the HTS and aligns with previous research both in Bogotá and elsewhere in Latin America (Ortegon-Sanchez and Oviedo Hernandez, 2016; Pritchard et al., 2019; Rosas-Satizábal and Rodriguez-Valencia, 2019). It is important to note that in addition to using Uber data as a proxy to private vehicles and assuming the cycling speed, for comparability purposes, the routes in both modes are the same as the one reported by the API. To estimate current cycling distances patterns in Bogotá, we also used the cycling trips in the survey. Taking advantage of the geo-location, we calculated the simulated route.

Travel data in the HTS was gathered between March 2015 and August 2015 by a private contractor of the Bogotá Government. The city was divided into Transport Analysis Zones (TAZ) and a sample of each zone was gathered. 28,212 households were surveyed, and 147,251 trips were registered and used to estimate 17,251,733 trips in the whole area of study on a typical working day. For private vehicles, 13,298 trips were registered, accounting for 1,831,397 expanded trips (10.62%). For cycling, 8157 trips were recorded accounting for 846,727 expanded trips. Databases and documents derived from the project are freely available on the SIMUR[4] and are maintained by the Secretaría de Movilidad[5] from the Colombian Open Data Portal[6]

3,210 out of 13,298 surveyed car-trips are not included in the analysis due to geo-referencing variables' inconsistencies. Other 448 trips with length trips above 50 km are also removed from the analysis as they are considered outliers. From North to South Bogotá is around 31 Km long, and from East to West is around 15 Km width. Considering the surrounding towns, trips with 50 km length are possible but trips larger than that

[4] https://www.simur.gov.co/portal-simur/datos-del-sector/encuestas-de-movilidad/ is the main link, though data is in a Google Drive folder: https://drive.google.com/drive/folders/0Bzyr0SveNi4AUWl3aC1fT2kzclk
[5] http://www.movilidadbogota.gov.co/web/node/1654 Secretaria de movilidad is one of the local transport authorities in Bogotá.
[6] For example, you can find the trips database here: https://www.datos.gov.co/Transporte/Encuesta-de-movilidad-de-Bogot-2015-Caracterizaci-/3pfx-f8dm

distance seem unlikely. Such errors can be attributed to either errors or inconsistencies in the longitude and latitude information in the HTS. Something similar happened to cycling trips, and we removed trips with long distances or with other inconsistencies.

The final dataset used for the analysis includes 9,640 car-based surveyed trips representing an expanded number of 1,661,226 trips, 90.1% of the total estimation.

4.2 Potential Accessibility Model

Modern transport and urban planning have relied on accessibility to reconcile transport and land-use interactions and inform decision-making, with accessibility measures dating as early as the 1920s (Batty, 2009; Levine, 2020). Hansen (1959) proposed one of the first accessibility definitions as “the potential of opportunities for interaction”. Other definitions include “the benefits provided by a transportation/land-use system” (Ben-Akiva and Lerman, 1979) and, “..the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations using a (combination of) transport mode(s)” (Geurs and van Wee, 2004).

Since Hansen’s formulation, accessibility has expanded in scope, mathematical applications, and associated data collection and use. Accessibility studies using General Transit Feed Specifications GTFS (Stępniak and Goliszek, 2017) and GPS data (Moya-Gómez and García-Palomares, 2017) are becoming more common, enabling further understanding of urban and transport phenomena. Accessibility has also been deployed as a relevant mechanism to analyse the distributional effects of transport. Research has recognised that the benefits of transport infrastructure investments are not evenly distributed across population groups and that lack of access to opportunities contributes to social exclusion (Lucas, 2019, 2012; Pereira et al., 2017). Authors arguing for transport justice place accessibility at the core of a fair transport system (Martens, 2012), despite scope for further development in conceptual and practical approaches to estimate the contributions of accessibility to social justice (Lucas et al., 2016b). Understanding accessibility inequalities and their distribution can contribute to developing strategies to reduce the social gap and become a tool to evaluate impact and externalities derived from transport infrastructure investments (Lucas et al., 2016a).

A milestone in accessibility research was the work by Geurs and van Wee (2004) who identified four groups of accessibility measures (infrastructure-based measures, location-based measures, person-based measures and utility-based measures) as well as four essential and interrelated components in measuring accessibility: the land-use component, referring to the distribution of activities and the confrontation of supply and demand for them; the transportation component, who describes the transport system considering effort to travel; the temporal component that reflects temporal constraints such as the availability of opportunities for different periods and people's available time; and finally, the individual component focusing on the specific characteristics of people. Accessibility models and measures trend to focus on one or more of those components.

In this work we use the specification of potential accessibility shown in equation 1, which has been deployed by previous research in the Bogotá during the last decade (Bocarejo S. and Oviedo H., 2012; Guzman et al., 2017), suggesting its applicability and relevance for the local context.

$$A_{is} = \sum_{j=1}^{n} O_j * exp(\beta_s * C_{ij}) \quad (1)$$

Where A_{is} is the accessibility of zone i for income group (strata) s; O_j represents the opportunities (jobs); C_{ij} is the generalised transport cost travelling between i and j, and for the specific case of this paper is only the travel time (we are not considering other costs); and β_s is a calibration parameter of car transport mode for each stratum. The generalised transport cost by origin-destination pair was calculated as the mean travel time of all the car-based trips with Uber's data. Different estimations of accessibility using Equation 1 have yielded relevant results concerning transport inequalities in access to mandatory and non-mandatory opportunities in various urban contexts (Benevenuto and Caulfield, 2019; Bocarejo et al., 2016, 2014; Oviedo and Guzman, 2020b). However, this is the first study comparing motorised and non-motorised accessibility, focusing on informing specific bike-sharing policies.

4.3 Criteria for informing bike-sharing implementation

The analysis of data through descriptive spatial analysis and accessibility are operationalised to identify priority zones that are most likely to benefit from modal shifts from the car to the bicycle. Seeking to address different social and operational objectives, the paper proposes a set of criteria seeking to maximise the potential benefits of shifts from the car to the bicycle in different domains: environmental, operational (efficiency), and social.

The first criterion responds to the environmental objective of reducing short-distance car trips, which have the highest air pollution rates by km. This criterion is based on travel distance, identifying zones that are generating car-based trips within cyclable distances. Two additional criteria are proposed to identify priority areas for implementation of bike-sharing to account for other relevant factors in cycling uptake that have the potential to maximise benefits of a modal shift from the car. The second criterion responds to objectives of efficiency, using travel time savings -a variable commonly used in mainstream transport planning as benchmark for efficiency- (Oviedo and Nieto-Combariza, 2021). This critetion will consider if a zone is in the highest quartile of travel time savings under substitution scenarios for trips below 10 km.

The third criterion responds to the social objective of maximising accessibility gains, a target highlighted in accessibility research as a way of increasing welfare benefits of urban transport (Bocarejo S. and Oviedo H., 2012; Pucci and Vecchio, 2019). This criterion will consider if a zone is in the highest quartile of accessibility gains. Combining these criteria enables prioritising areas that might best illustrate the benefits of a more general bike-sharing policy. In this exercise, a TAZ meeting two of the above criteria will be identified as a candidate for implementing bike-sharing, and to foster sustainable modal shifts.

5. Findings: Bogotá's unrealised cycling potential

5.1. Car vs. Bicycle

The first part of the analysis explored travel distances covered by car trips in Bogotá compared to cycling trips in search of similarities and differences related to mode-specific travel patterns. Data from Bogotá's HTS suggest that bicycle users in Bogotá do mostly short trips. As shown in Figure 3, most cyclists in Bogotá commute less than 5 km in a single trip. Such a figure is a relevant benchmark for the analysis of *cyclable* car-based trips. When considering a gender lens for the analysis of cycling trips, two issues become evident. On the one hand, the proportion of female cyclists is much smaller than male cyclists' proportion. On the other hand, most women cyclists make shorter trips than men: mean travelled distance for men is 5.44 Km and for women is 4.08 Km. Shorter distances for women can be linked with more trip chaining and more local mobility of women associated with time restrictions imposed by care responsibilities and other socially constructed roles (Grudgings et al., 2018; Mackintosh and Norcliffe, 2012; Steinbach et al., 2011).

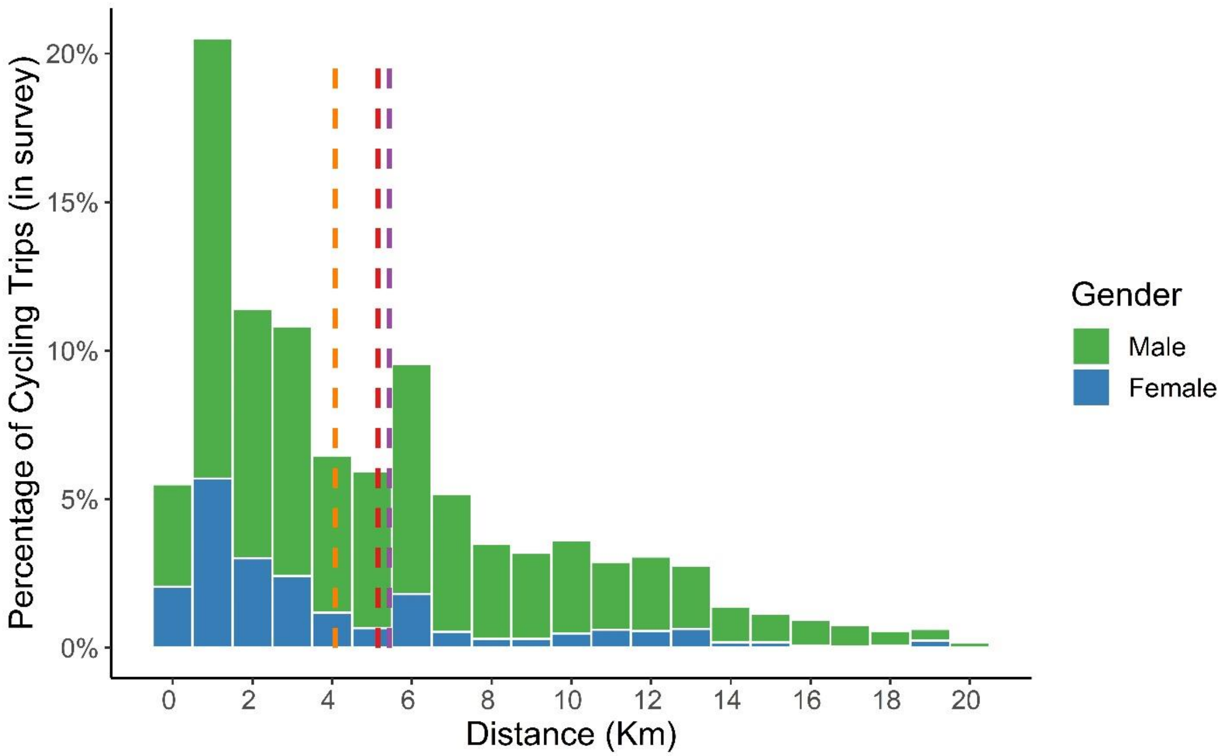


Fig. 3. Histogram of cycling trips by distance and gender[7]

Source: Own elaboration based on data from Bogotá's HTS (2017)

The paper analysed the distribution of distances in car-based trips using the distribution of cycling distances as a point of reference. As shown in Figure 4, the cumulative distribution of car trips in Bogotá reflects that most car journeys are short. 11.5% of the trips cover less than 2 km, over 343 thousand trips (21%) cover less than 3 km and 40% (672,162 trips) are below 4 km. As with cycling, about 80% of car-based trips are below 10 km, suggesting a large share of these displacements -made by non-disabled citizens- that could be transferred to the bicycle. When looking at the distribution of car trips by distance and gender, it becomes clear that women use less the car than men, at least in terms of the total number of trips they make on this mode. Comparisons by gender with the bicycle suggest that many car trips are between 5 and 10 km and that roughly 20% of displacements by men and women are unlikely to be transferred to the bicycle given their long distance.

[7] Red line corresponds to the overall mean value (5.15 Km), orange line corresponds to mean value for females (4.08 Km) and purple line correspond for mean values for males (5.44 Km).

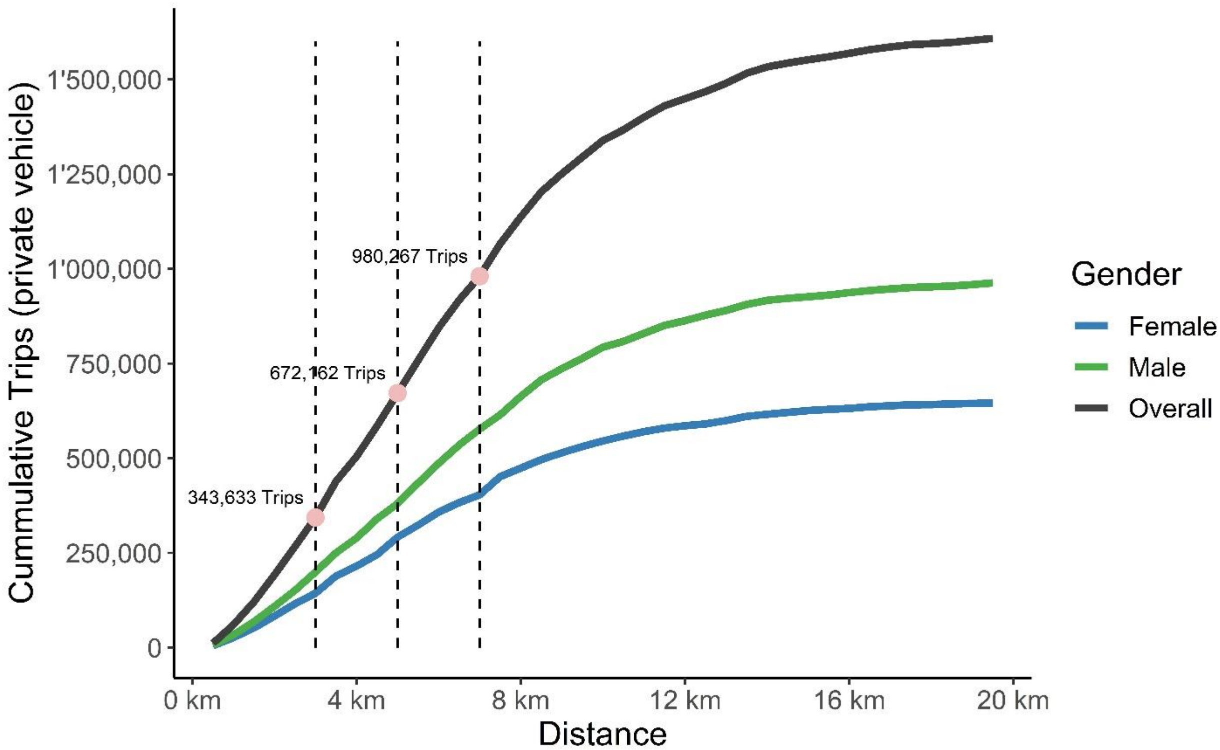


Fig. 4. Cumulative distribution of car trips by travel distance.

Source: Own elaboration based on data from Bogotá's HTS (2017)

Half of the car-based trips in the city are made at distances below 6 km. The spatial distribution of travel distance across the city suggests that making short trips via private vehicles is somewhat dispersed across Bogotá. TAZ generating trips with mean travel distances below 5 km spread throughout higher and lower income areas, as shown in Figure 5. However, from a social inequalities perspective, it is notable that TAZ with the highest average travel distances concentrates on the southern side of Bogotá. As shown in Figure 1, this area of the city not only concentrates most lower-income populations, but it also has a lower availability of local employment opportunities. As suggested by previous research, motorised accessibility is lower in the southern neighbourhoods, with car-based travel being an alternative for a comparatively lower share of the population in low-income communities for reaching employment despite these areas making longer trips (Guzman et al., 2017).

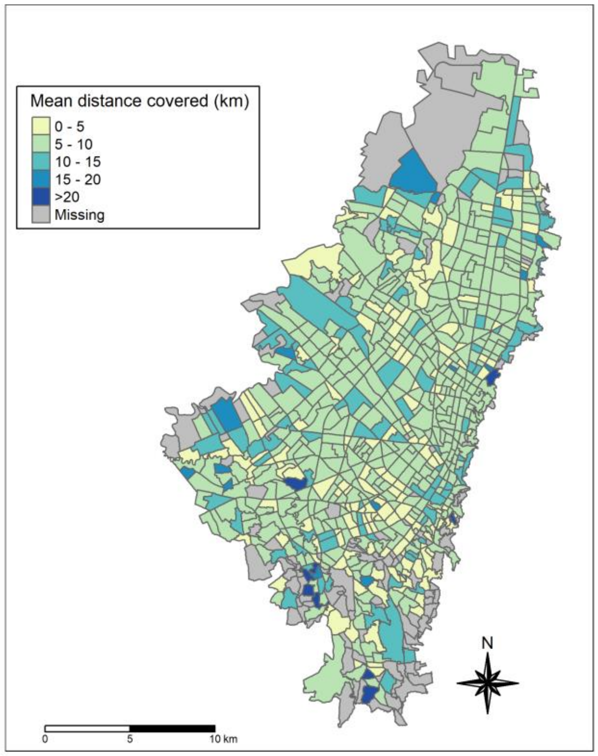


Fig. 5. Mean car-based trip distance by TAZ.
Source: Own elaboration based on data from Bogotá's HTS (2017)

We deployed comparisons in travel time differences to examine whether modal shifts in car-based trips made at *cyclable* distances could entail travel time savings. Figure 6 (left) shows the distribution of the difference of times (trip by trip considering three different cycling speed values), suggesting that cycling can outperform car-based trips in terms of travel times in a large share of cases. As shown in Figure 6 (right), 34.8% (577,829 trips) would have the same or less travel time assuming 11.5 Km/h as speed value. If the speed increases to 14.5 Km/h, then 68.6% (1,139,305 trips) would have the same or less travel time. The spatial distribution of the differences (for the three speeds analysed) is presented in Figure 7. As shown in Figure 7, only a handful of TAZ present loses in travel time, in many cases, due to longer travel distances and peripheral locations. A notable finding in the spatial analysis of travel time differences between car and equivalent cycling trips is that almost all areas experiencing travel time loses are middle and low-SES (refer to Figure 1 for the SES distribution).

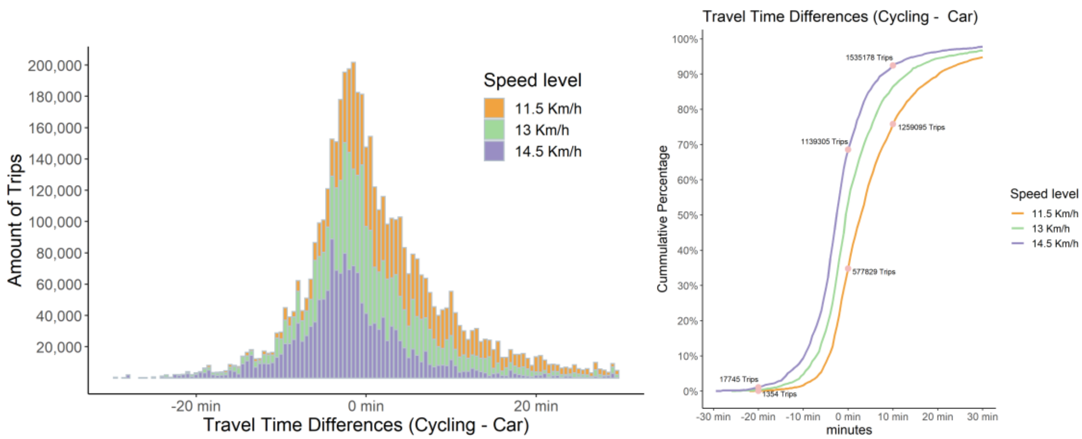
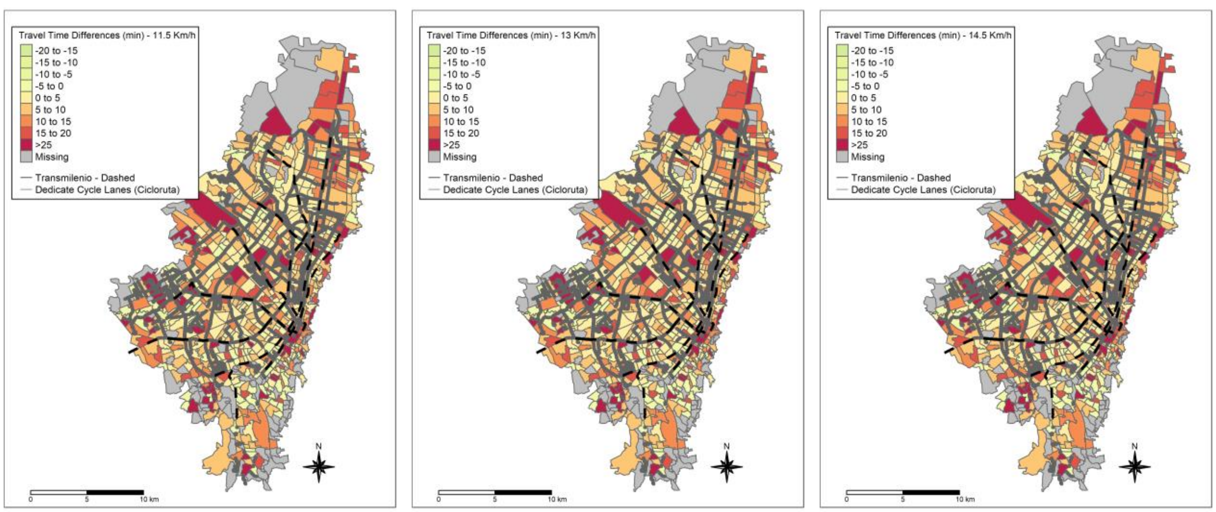


Fig. 6. Histogram of travel times differences (left) and Cumulative Percentage of time savings (right)

Source: Own elaboration based on data from Bogotá’s HTS (2017)



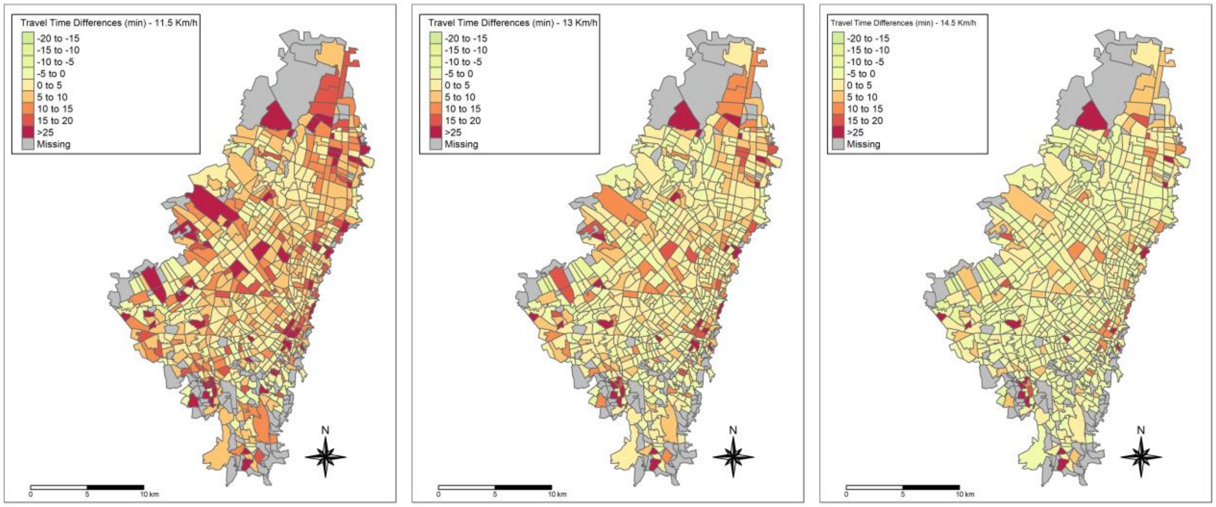


Fig. 7. Mean travel time differences (Cycling - Car) by TAZ.

Source: Own elaboration based on data from Bogotá's HTS (2017)

Figure 8 shows the mean value of travel time differences (y-axis) for trips grouped every 500 meters. For the 11.5 Km/h speed, car trips become faster (on average) at 4 Km. The distance becomes 7 Km for 13 Km/h and 10.5 Km for 14.5 Km/h, suggesting that the car tends to improve access for populations farther from the main centres of activity, which tend to have low SES. Appendix A summarises the total trips made for different distance intervals and the number of trips faster if made using bicycles. A 100% (60,232) of car trips with distances below 2 km would be more efficient if done cycling (assuming a speed of 14.5 Km/h).

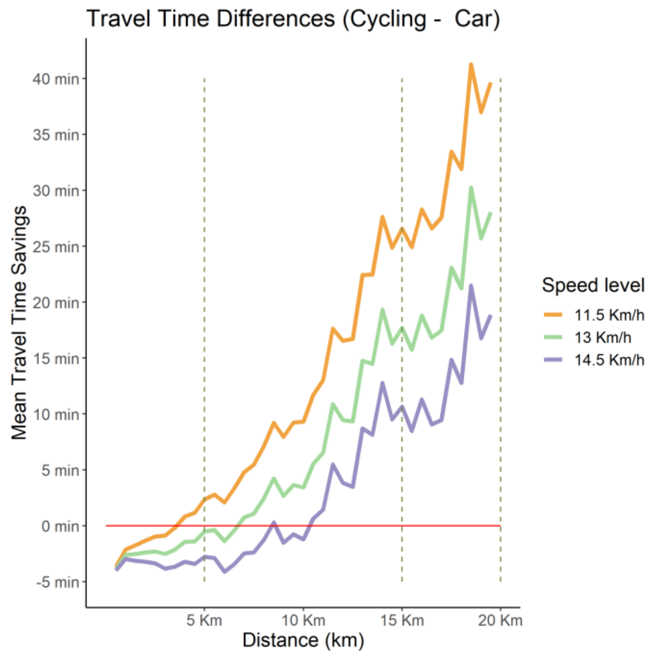


Fig. 8 Mean travel time differences (Cycling - Car) by distances.
Source: Own elaboration based on data from Bogotá's HTS (2017).

5.2. Accessibility

Potential accessibility functions were estimated by SES, linking the impedance in Equation 1 with observable differences in income (see Table 1). For this part of the analysis, we only use a speed of 13.5 Km/h. Figure 9 shows that the overall accessibility (in terms of number of reachable jobs) improves for all SES under a scenario of total substitution of car-based trips by cycling trips. SES 3 and 4 would be the most benefited, suggesting their location and travel behaviour would be the most adaptable to cycling. Therefore, the more considerable benefits of implementing bike-sharing concentrate in these neighbourhoods. By contrast, SES 1 shows lower positive effects of the hypothetical modal shift, though it can increase accessibility by cycling. SES 1 has limited access to private vehicles. The social and spatial structure of Bogotá has led to SES 1 being mostly concentrated in the peripheries, far from the city centre's employment hotspots. SES 5 and 6 also experience lower improvements in accessibility, despite being near employment hotspots and usually well-served by Transmilenio. In TAZ located near the centre, we observed accessibility losses if shifting from car to cycling (Fig. 10).

Strata	Beta	R2
1	-0.102	0.745
2	-0.098	0.781
3	-0.109	0.715

4	-0.115	0.693
5	-0.110	0.705
6	-0.105	0.734

Table 1. Accessibility Coefficients and R2 for the 6 models (one for every strata)
Source: Own elaboration based on data from Bogotá's HTS (2017)

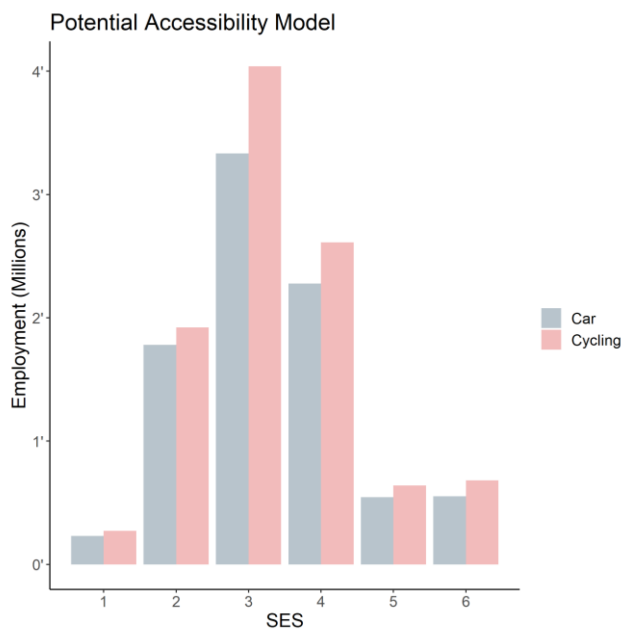


Fig. 9. Accessibility differences by SES
Source: Own elaboration based on data from Bogotá's HTS (2017)

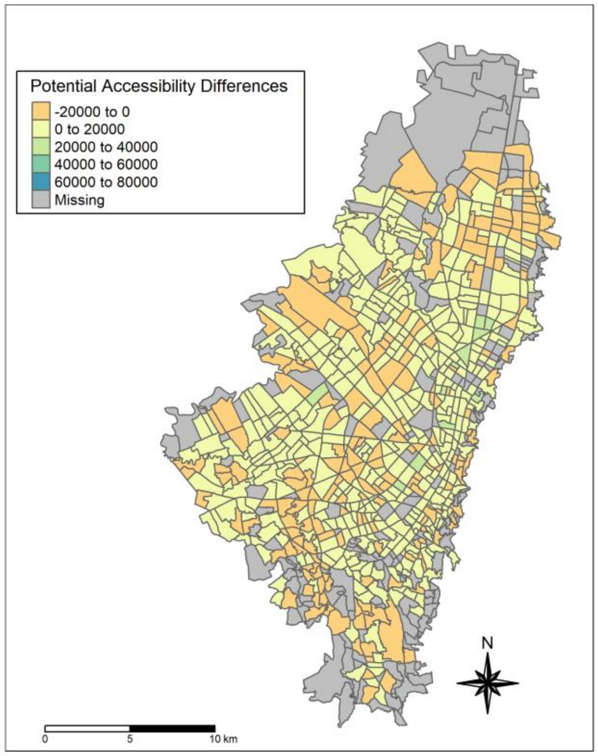


Fig. 10. Spatial distribution differences in accessibility (Cycling - Car).
Source: Own elaboration based on data from Bogotá's HTS (2017)

Recognising that total mode substitution is unlikely, even among trips conducted at *cyclable* distances, Figure 11 and Appendix B show the sensibility of accessibility under different proportions of modal shift from the car to the bicycle. This analysis builds on the likelihood of modal shift given travel time savings by bicycle, *cyclable* distances, and supporting infrastructure availability. SES are aggregated in three categories: Low (SES 1 and 2), Medium (SES 3 and 4) and High (SES 5 and 6). Evidence shows apparent differences between categories, with Medium SES being able to reap the most considerable benefits from modal shifts from the car to the bike.

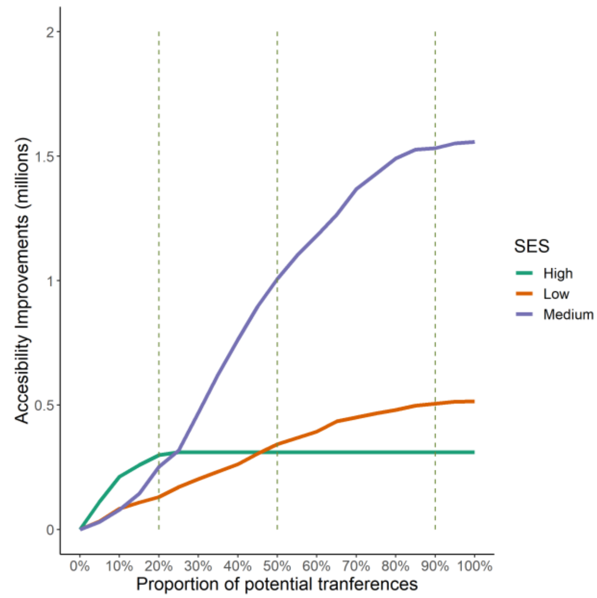


Fig. 11. Sensibility of accessibility under different proportions of modal shifts. Source: Own elaboration based on data from Bogotá's HTS (2017)

5.3. Estimating the potential for bike-sharing as a mechanism for supporting sustainable mobility

Analysis in previous sub-sections suggests Bogotá's potential to leverage cycling for a more efficient, healthy, and sustainable urban mobility. We deployed arguments common in mainstream transport planning, such as an increase in efficiency and travel time savings, translated in overall gains in accessibility, particularly for Middle and Low SES households. The first criterion is the distance, identifying the zones that are generating car-based trips within cyclable distances. Average cycling distance in Bogotá is 5.1 km. However, as shown in Figure 3, males commute more by bike (72%) than females (28%), with the first travelling longer distances. The average distance for women cyclists is 4.1 km, whilst male cyclists' average distance is 5.4 km. Criterion 1 is estimated at a cut-off of 3 km.

As shown in Figure 5, there is a widespread distribution of car-based travel within cyclable distances across Bogotá. A relevant number of TAZ identified under criterion 1 belonging to middle and low SES and near both BRT and cycle lanes infrastructure and account for 2.17% out of the total car-base trips in the study zone. Two additional criteria were used as explained in section 3.3. Criterion 2 considers if a zone is in the highest quartile of travel time savings under substitution scenarios for trips below 10 km. Criterion 3 considers if a zone is in the highest quartile of accessibility gains. Combining these criteria enables prioritising areas that might best illustrate the benefits of a more general bike-sharing policy. The zones with the largest potential to benefit from and to foster sustainable modal shifts are displayed in Figure 12. The total candidate zones account for 496,467 inhabitants.

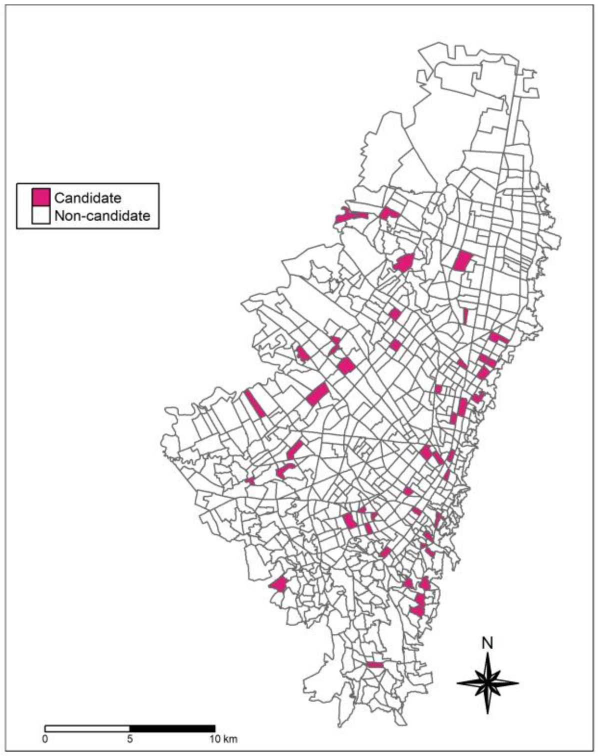


Fig. 12. Zones with higher potential for bike-sharing
Source: Own elaboration based on data from Bogotá's HTS (2017)

Results shown in Figure 12 reflect a dispersed distribution of candidate zones across the city. Despite such spatial dispersion, the selected zones represent a balance between operational, environmental and social benefits of modal shifts to the bicycle. The potential implementation of bike-sharing in these zones can act as a catalyst for the widespread adoption of bike-sharing in adjacent corridors already covered by the cycling infrastructure in the city between zones selected for prioritisation of bike-sharing. It is important to note that the selected candidate zones respond to criteria based on the benefits for the resident population. These zones can lead to a more equitable distribution of benefits than traditional approaches to the development of bike-sharing systems seeking to maximise revenue or to serve only areas with higher attractiveness. However, our proposal can only be feasible if additional resources are devoted to extend access to the system in areas of high attraction of demand to enhance accessibility to the bicycle in both travel directions.

6. Discussion

This paper presents Bogotá's untapped potential for cycling, emphasising the benefits for commuters making the shift between cars and bicycles. Our analysis taps on the idea of implementing a cycling policy that has not yet taken flight, bike-sharing, in a city otherwise recognised for taking bold steps towards improving urban mobility, mainly through infrastructure (Montero, 2020). To move people away from car-based mobilities towards a mode that can sometimes be underestimated in terms of efficiency such as the bicycle, can lead to significant benefits in travel times and accessibility to employment. This work attempts to contribute further to research already deploying more classic arguments focused on environmental and health positive externalities. Combining these findings with previous research seeks to consolidate an argument often said but not always proven: cycling is more efficient than using cars.

Above 50% of the current car-based trips in the city are below 6 kilometres, a distance that can be easily covered by bicycle for a majority of able-bodied men and women. Furthermore, roughly 80% of car-based trips could experience travel time savings if shifting to cycling, and around 5% of the trips could save between 20 and 30 minutes each. It is essential to highlight that the significant policy challenge for local authorities in Bogota is to take advantage of the vast potential for cycling that the city currently has. Such a challenge can be addressed by designing and implementing a large-scale bike-share system, increasing cycling infrastructure while reducing private vehicles' space, or other complementary strategies. Nevertheless, any policy should consider that as people start shifting from cars to bicycles, it is likely that congestion will reduce and therefore, people could feel more attracted to come back to car mobilities. This study does not evaluate such an effect, but the general recommendation is to monitor modal shift and repeatedly avoid the car becoming an attractive option. While large scale shifts in mode use before the COVID-19 crisis were less likely, anecdotal evidence from Bogotá and elsewhere suggests a more open attitude towards cycling supported by an explicit policy stance fostering the uptake of the bicycle instead of motorised alternatives. Findings are also aligned with international urban development agendas mediated by sustainability and social justice objectives where scholars and practitioners have repeatedly highlighted the need to reduce and regulate car use.

The analysis of potential accessibility impacts on employment provides further arguments in favour of cycling. In a hypothetical full modal shift scenario, all income groups would experience accessibility gains. However, under all scenarios, middle-income groups would benefit the most. Considering that these groups trend to live in the central places of Bogotá, that are also most likely to increase their uptake of private motorisation in the sort and medium-term, and that are more influenced by restrictive measures against car use according to previous research in Bogotá (Combs and Rodríguez, 2014; Gomez-Gelvez and Obando, 2013; Mahendra, 2008), it is expected that a potential bike-share system becomes almost exclusively a middle class policy. This should not be the exclusive aim of a bike-share system and a future (and detailed) evaluation should consider pathways to extent benefits to socially excluded groups and to drop car usage among the richer population. To provide arguments related to their benefits and efficiency might be more effective than the traditional approach to curb motorisation through circulation restrictions and pricing. A combination of push and pull policies can contribute to maximise positive results int his regard.

We address bike-sharing in light of findings as a policy mechanism that can contribute to fostering cycling to increase sustainability and efficiency in urban mobility in Bogotá. Results are the first indication of unrealised potential for cycling and the evidence of arguments favouring cycling as an alternative to private cars rather than definitive planning guidance for implementing bike-sharing. Findings complement previous research by identifying the accessibility potential of areas producing potentially cyclable and more efficient trips with a backdrop of the most relevant transport infrastructure for sustainable mobility. Placing permanent cycle lanes as part of the context of the prioritisation shown in Figure 14 makes it evident for the reader that the current infrastructure network is already serving a majority of TAZ with the largest potential to profit from fostering cycling among car users through bike-sharing. This evidence supports already established indications of cycle lanes' role in fostering further cycling (Rodriguez-Valencia et al., 2019).

By exploring some of the differences by gender in the behaviour of both cyclists and car users, some factors emerge that require further research in the local context. Despite the limited depth of our analysis concerning intersectional determinants of cycling and car use, differences among women and men of different SES become evident from statistical and spatial findings in this paper. This suggests that some users may still not shift from the car to the bike even with access to adequate infrastructure given complexities beyond efficiency, access and time savings. Affordability is a relevant concern, although the comparison with car users and findings of higher benefits among middle-SES households suggest this may be less of an issue for the target population. Nonetheless, aspirational values associated with the car and potential stigmas and fear of crime associated with the bicycle might reduce the bicycle uptake in many of the socio-economic sectors that from the perspective shown in this paper would benefit the most.

Attitudinal and civic culture campaigns such as those deployed in the city in the early 2000s with the explicit aim of enticing behavioural change with positive results (Gilbert, 2015), could go a long way in supporting infrastructure and bike-sharing systems. Other social concerns such as crime, the temporal dimension of both car-based and cycling travel demand, and people's physical and cognitive ability to use bike-sharing systems are issues that merit further exploration.

7. Conclusions

While it seems self-evident, we can conclude that bicycles are a competitive alternative to cars under most circumstances in Bogotá. Such a simple conclusion manifests differently across social groups and the city's geography, and it has different potential implications for accessibility, efficiency, and sustainability. Findings in this paper suggest that those in a more advantaged social, economic and spatial position would likely benefit the most from a shift to the bicycle and implementing policies such as bike-sharing. Historically, the uptake of cycling among middle and high SES households has been slower than their growing car use. This is an opportunity for Bogotá to adopt more carrot and less stick concerning its policies to curb congestion and private motorisation. Arguments in this paper provide some elements to better-place the bicycle as a viable alternative to the car, and to prioritise implementation of bike-sharing where it could reduce the most the use of private vehicles, while still securing positive effects towards social and environmental objectives. Such a strategy may foster widespread benefits for society in reducing congestion and pollution in areas of the city with heavy traffic, and identifying areas where accessibility benefits of the bike can be comparatively larger. In the context of response to the COVID-19 crisis, and other potential health emergencies to face our cities in the future, these results become more relevant as many urban residents take a more open attitude towards walking and cycling and step away from public transport.

Despite its positive track record in urban planning and development, Bogotá is still grappling with the challenges associated with daily urban mobility, while trying to define its trajectory as a sustainable city (Oviedo and Guzman, 2020a). This is best exemplified by many efforts in the past to implement a bike-sharing system that has not yet materialised, having to give priority to more critical infrastructure and transport investments. The priority TAZ identified in this paper suggest a potentially less ambitious but more profitable approach to kickstart bike-sharing in a city that has already gone a long way in providing the required infrastructure to support a public bicycles system. There is a clear trade-off involved in the results concerning the limited focus on low-income areas. While findings suggest that all SES could benefit from implementing bike-sharing, low-income areas might benefit more from a policy integrating cycling with public transport given long travel distances from the peripheries. This paper aims not to solve all challenges related to increasing cycling uptake in Bogotá through bike-sharing. We recognise the limitations of small-scale implementations to reduce social and spatial inequalities, including improving access to bicycles and cycle lanes in low-income neighbourhoods. Instead, the paper proposes a strategy that may fit well with current agendas to demonstrate the potential benefits of bike-sharing and contribute to breaking the inertia that so far has prevented such systems from taking off successfully. Moreover, by shifting the rhetoric towards swaying car users, the paper also provides elements to reconcile often separated policy stances in relation to the car and bicycles as separate target groups.

The article also speaks to civil society, and advocacy groups in the city, who have historically played an essential role in fostering cycling (Castañeda, 2020). Despite cycling's relevance for the environment, health, and the exercise of the right to the city, arguments of efficiency and utility take precedence in transport decision-making. This is partly a consequence of the long tradition of "neutral" engineering and economic concepts and methods underpinning transport planning. Evidence such as those presented in the paper helps find a common language between technical and social disciplines and practitioners concerned with transport planning. Aligning agendas based on the evidence can lead to a more inclusive and equitable approach to cycling as part of a consistent vision of the city. This paper illustrates the relevance of targeted arguments for placing cycling as an alternative to the many detrimental effects of the car, particularly for those currently "benefitting" from its use. This, in turn, may foster further changes down the line, supporting the reallocation of resources and scaling-up of initiatives such as bike-share implementation so they can achieve the necessary positive social and environmental effects all transport policies should pursue.

The results are a starting point to foster further research that can lead to a more formal design of at least a pilot bike-sharing system in the city. Findings seek to increase the odds of success of limited investments to leverage middle and long-term transformations that target other parts of the city. A clear priority for follow-up interventions is using bike-sharing to improve the connectivity with the mass transit network, particularly in low-income neighbourhoods. Further research is necessary to assess such an alternative.

It is important to acknowledge that while the paper's focus on car trips to employment responds to a rising concern with the city's increasing motorisation rates, the study has some limitations that open avenues for further research. First, it cannot shed light on non-commuting cycling trips. There is need to explore multi-activity accessibility (Cui and Levinson, 2020) in further research to examine the role of cycling and bike-sharing in addressing more complex travel patterns and motivations. Second, we do not evaluate the possibility of integration with transportation systems in the first/last mile trip. An additional limitation related to the API simulation data is assuming cycling trips will follow the same paths as the Uber trips and on the same infrastructure. Cycling lanes in the city can provide additional flexibility to cycling trips. However, the research does not use routing simulations that can account for such flexibility, which may lead to underestimating the effect of cycle lanes in some trips. Future research should incorporate these parameters to examine more in detail the role of infrastructure in the effectiveness of bike-sharing.

References

Alcaldía de Bogotá (2020). Con 22 km. de ciclovía la alcaldía busca descongestionar TransMilenio, viewed 7 July 2020, <https://bogota.gov.co/mi-ciudad/coronavirus-covid-19-con-ciclovia-se-descongestionara-transmilenio>

Alcaldía de Bogotá (2020). Bogotá ya cuenta con 30108 biciparqueaderos, viewed 30 June, <https://bogota.gov.co/mi-ciudad/movilidad/hay-3108-biciparqueaderos>

Alcaldía de Bogotá (2018). Decreto 456 de 2018, viewed 30 June, <https://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=80486>

Bachand-Marleau, J., Lee, B., El-Geneidy, A., 2012. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. Transp. Res. Rec. 2314, 66–71. https://doi.org/10.3141/2314-09

Batty, M., 2009. Accessibility: In search of a unified theory. Environ. Plan. B Plan. Des. 36, 191–194. https://doi.org/10.1068/b3602ed

Benevenuto, R., Caulfield, B., 2019. Poverty and transport in the global south: An overview. Transp. Policy 79, 115–124. https://doi.org/10.1016/j.tranpol.2019.04.018

Bocarejo, J.P., Escobar, D., Hernandez, D.O., Galarza, D., 2016. Accessibility analysis of the integrated transit system of Bogotá. Int. J. Sustain. Transp. 10, 308–320. https://doi.org/10.1080/15568318.2014.926435

Bocarejo, J.P., Portilla, I.J., Velásquez, J.M., Cruz, M.N., Peña, A., Oviedo, D.R., 2014. An innovative transit system and its impact on low income users: The case of the Metrocable in Medellín. J. Transp. Geogr. 39, 49–61.

https://doi.org/10.1016/j.jtrangeo.2014.06.018

Bocarejo S., J.P., Oviedo H., D.R., 2012. Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments. J. Transp. Geogr. 24, 142–154. https://doi.org/10.1016/j.jtrangeo.2011.12.004

Buehler, R., Dill, J., 2016. Bikeway Networks: A Review of Effects on Cycling. Transp. Rev. 36, 9–27. https://doi.org/10.1080/01441647.2015.1069908

Castañeda, P., 2020. From the Right to Mobility to the Right to the Mobile City: Playfulness and Mobilities in Bogotá's Cycling Activism. Antipode 52, 58–77. https://doi.org/10.1111/anti.12581

Cervero, R., 2002. Built environments and mode choice: Toward a normative framework. Transp. Res. Part D Transp. Environ. 7, 265–284. https://doi.org/10.1016/S1361-9209(01)00024-4

Cervero, R., Sarmiento, O.L., Jacoby, E., Gomez, L.F., Neiman, A., 2009. Influences of built environments on walking and cycling: Lessons from Bogotá. Int. J. Sustain. Transp. 3, 203–226. https://doi.org/10.1080/15568310802178314

Clark, J., Curl, A., 2016. Bicycle and Car Share Schemes as Inclusive Modes of Travel? A Socio-Spatial Analysis in Glasgow, UK. Soc. Incl. 4, 83–99. https://doi.org/10.17645/si.v4i3.510

Combs, T.S., Rodríguez, D.A., 2014. Joint impacts of Bus Rapid Transit and urban form on vehicle ownership: New evidence from a quasi-longitudinal analysis in Bogotá, Colombia. Transp. Res. Part A Policy Pract. 69, 272–285. https://doi.org/10.1016/j.tra.2014.08.025

Cui, M., Levinson, D., 2020. Multi-activity access: How activity choice affects opportunity. Transp. Res. Part D Transp. Environ. 85, 102364. https://doi.org/10.1016/j.trd.2020.102364

Deka, D., 2018. Bicycle justice and urban transformation: biking for all?, Transport Reviews. Routledge. https://doi.org/10.1080/01441647.2017.1311965

Duran-Rodas, D., Villeneuve, D., Pereira, F.C., Wulfhorst, G., 2020. How fair is the allocation of bike-sharing infrastructure? Framework for a qualitative and quantitative spatial fairness assessment. Transp. Res. Part A Policy Pract. 140, 299–319. https://doi.org/10.1016/j.tra.2020.08.007

Faghih-Imani, A., Anowar, S., Miller, E.J., Eluru, N., 2017. Hail a cab or ride a bike? A travel time comparison of taxi and bicycle-sharing systems in New York City. Transp. Res. Part A Policy Pract. 101, 11–21. https://doi.org/10.1016/j.tra.2017.05.006

Fishman, E., 2016. Bikeshare: A Review of Recent Literature. Transp. Rev. 36, 92–113. https://doi.org/10.1080/01441647.2015.1033036

Fishman, E., Schepers, P., 2016. Global bike share: What the data tells us about road safety. J. Safety Res. 56, 41–45. https://doi.org/10.1016/j.jsr.2015.11.007

Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. J. Transp. Geogr. 12, 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Gilbert, A., 2015. Urban governance in the South: How did Bogotá lose its shine? Urban Stud. 52, 665–684. https://doi.org/10.1177/0042098014527484

Gomez-Gelvez, J., Obando, C., 2013. Modeling car ownership in urban areas of developing countries. Transp. Res. Rec. 2394, 111–118. https://doi.org/10.3141/2394-14

Grudgings, N., Hagen-Zanker, A., Hughes, S., Gatersleben, B., Woodall, M., Bryans, W., 2018. Why don't more women cycle? An analysis of female and male commuter cycling mode-share in England and Wales. J. Transp. Heal. 10, 272–283. https://doi.org/10.1016/j.jth.2018.07.004

Gutiérrez, M., Cantillo, V., Arellana, J., Ortúzar, J. de D., 2020. Estimating bicycle demand in an aggressive environment. Int. J. Sustain. Transp. https://doi.org/10.1080/15568318.2020.1734886

Guzman, L.A., Arellana, J., Alvarez, V., 2020. Confronting congestion in urban areas: Developing Sustainable Mobility Plans for public and private organizations in Bogotá. Transp. Res. Part A Policy Pract. 134, 321–335. https://doi.org/10.1016/j.tra.2020.02.019

Guzman, L.A., Bocarejo, J.P., 2017. Urban form and spatial urban equity in Bogota, Colombia. Transp. Res. Procedia 25, 4491–4506. https://doi.org/10.1016/j.trpro.2017.05.345

Guzman, L.A., Oviedo, D., Rivera, C., 2017. Assessing equity in transport accessibility to work and study: The Bogotá region. J. Transp. Geogr. 58, 236–246. https://doi.org/10.1016/j.jtrangeo.2016.12.016

Hackl, A., 2018. Mobility equity in a globalized world: Reducing inequalities in the sustainable development agenda. World Dev. 112, 150–162. https://doi.org/10.1016/j.worlddev.2018.08.005

Hansen, W.G., 1959. How Accessibility Shapes Land Use. J. Am. Plan. Assoc. 25, 73–76. https://doi.org/10.1080/01944365908978307

Heinen, E., van Wee, B., Maat, K., 2010. Commuting by bicycle: An overview of the literature. Transp. Rev. 30, 59–96. https://doi.org/10.1080/01441640903187001

INRIX, 2020. Global Traffic Scorecard [WWW Document]. INRIX Res.

Instituto Distrital de Recreación y Deporte - IDRD, 2020. Muévete Bogotá | INSTITUTO DISTRITAL DE RECREACIÓN Y DEPORTE [WWW Document]. URL https://www.idrd.gov.co/ciclovia-bogotana (accessed 10.5.21).

Larsen, J., Patterson, Z., El-Geneidy, A., 2013. Build It. But Where? The Use of Geographic Information Systems in Identifying Locations for New Cycling Infrastructure. Int. J. Sustain. Transp. 7, 299–317. https://doi.org/10.1080/15568318.2011.631098

Levine, J., 2020. A century of evolution of the accessibility concept. Transp. Res. Part D Transp. Environ. 83, 102309. https://doi.org/10.1016/j.trd.2020.102309

Lortie, C., 2017. R for Data Science , First Edit. ed, Journal of Statistical Software. O'Reilly Media, Inc. https://doi.org/10.18637/jss.v077.b01

Lovelace, R., Nowosad, J., Muenchow, J., 2019. Geocomputation with R, Geocomputation with R. CRC Press. https://doi.org/10.1201/9780203730058

Lucas, K., 2019. A new evolution for transport-related social exclusion research? J. Transp. Geogr. 81, 102529. https://doi.org/10.1016/j.jtrangeo.2019.102529

Lucas, K., 2012. Transport and social exclusion: Where are we now? Transp. Policy 20, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013

Lucas, K., Mattioli, G., Verlinghieri, E., Guzman, A., 2016a. Transport poverty and its adverse social consequences. Proc. Inst. Civ. Eng. Transp. 169, 353–365. https://doi.org/10.1680/jtran.15.00073

Lucas, K., van Wee, B., Maat, K., 2016b. A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. Transportation (Amst). 43, 473–490. https://doi.org/10.1007/s11116-015-9585-2

Mackintosh, P.G., Norcliffe, G., 2012. Men, Women, and the Bicycle: Gender and Social Geography of Cycling in the Late Nineteenth-Century, in: Horton, D., Rosen, P., Cox, P. (Eds.), Cycling and Society. Ashgate, Hampshire, England, p. 205.

Mahendra, A., 2008. Vehicle restrictions in four latin American cities: Is congestion pricing possible? Transp. Rev. 28, 105–133. https://doi.org/10.1080/01441640701458265

Martens, K., 2012. Justice in transport as justice in accessibility: Applying Walzer's "Spheres of Justice" to the transport sector. Transportation (Amst). 39, 1035–

1053. https://doi.org/10.1007/s11116-012-9388-7

Médard de Chardon, C., 2019. The contradictions of bike-share benefits, purposes and outcomes. Transp. Res. Part A Policy Pract. 121, 401–419. https://doi.org/10.1016/j.tra.2019.01.031

Médard de Chardon, C., Caruso, G., Thomas, I., 2017. Bicycle sharing system ‘success’ determinants. Transp. Res. Part A Policy Pract. 100, 202–214. https://doi.org/10.1016/j.tra.2017.04.020

Médard de Chardon, C., Caruso, G., Thomas, I., 2016. Bike-share rebalancing strategies, patterns, and purpose. J. Transp. Geogr. 55, 22–39. https://doi.org/10.1016/j.jtrangeo.2016.07.003

Montero, S., 2020. Leveraging Bogotá: Sustainable development, global philanthropy and the rise of urban solutionism. Urban Stud. 57, 2263–2281. https://doi.org/10.1177/0042098018798555

Montero, S., 2017. Worlding Bogotá’s Ciclovía. Lat. Am. Perspect. https://doi.org/10.1177/0094582X16668310

Mora, R., Moran, P., 2020. Public Bike Sharing Programs Under the Prism of Urban Planning Officials: The Case of Santiago de Chile. Sustainability 12, 5720. https://doi.org/10.3390/su12145720

Moya-Gómez, B., García-Palomares, J.C., 2017. The impacts of congestion on automobile accessibility. What happens in large European cities? J. Transp. Geogr. 62, 148–159. https://doi.org/10.1016/j.jtrangeo.2017.05.014

Ortegon-Sanchez, A., Oviedo Hernandez, D., 2016. Assessment of the potential for modal shift to non-motorised transport in a developing context: Case of Lima, Peru. Res. Transp. Econ. 60, 3–13. https://doi.org/10.1016/j.retrec.2016.05.010

Oviedo, D., Granada, I., Perez-Jaramillo, D., 2020. Ridesourcing and travel demand: Potential effects of transportation network companies in Bogotá. Sustain. 12, 1732. https://doi.org/10.3390/su12051732

Oviedo, D., Guzman, L., 2020a. Transportation Planning and Development in Bogotá, in: Rukmana, D. (Ed.), The Routledge Handbook of Planning Megacities in the Global South. Routledge, New York, NY, pp. 133–146. https://doi.org/10.4324/9781003038160-10

Oviedo, D., Guzman, L.A., 2020b. Revisiting accessibility in a context of sustainable transport: Capabilities and inequalities in Bogota. Sustain. 12, 4464. https://doi.org/10.3390/su12114464

Oviedo, D., Nieto-Combariza, M., 2021. Transport Planning in the Global South. Int. Encycl. Transp. 118–124. https://doi.org/10.1016/B978-0-08-102671-7.10624-4

Oviedo Hernandez, D., Dávila, J.D., 2016. Transport, urban development and the peripheral poor in Colombia - Placing splintering urbanism in the context of transport networks. J. Transp. Geogr. 51, 180–192. https://doi.org/10.1016/j.jtrangeo.2016.01.003

Oviedo Hernandez, D., Titheridge, H., 2016. Mobilities of the periphery: Informality, access and social exclusion in the urban fringe in Colombia. J. Transp. Geogr. 55, 152–164. https://doi.org/10.1016/j.jtrangeo.2015.12.004

Pebesma, E., 2018. Simple features for R: Standardized support for spatial vector data. R J. 10, 439–446. https://doi.org/10.32614/rj-2018-009

Pereira, R.H.M., Schwanen, T., Banister, D., 2017. Distributive justice and equity in transportation. Transp. Rev. 37, 170–191. https://doi.org/10.1080/01441647.2016.1257660

Pritchard, J.P., Tomasiello, D.B., Giannotti, M., Geurs, K., 2019. Potential impacts of bike-and-ride on job accessibility and spatial equity in São Paulo, Brazil. Transp. Res. Part A Policy Pract. 121, 386–400. https://doi.org/10.1016/j.tra.2019.01.022

Pucci, P., Vecchio, G., 2019. Enabling mobilities: Reinterpreting concepts and tools, in: SpringerBriefs in Applied Sciences and Technology. Springer Verlag, pp. 1–9. https://doi.org/10.1007/978-3-030-19581-6_1

Pucher, J., Buehler, R., 2017. Cycling towards a more sustainable transport future. Transp. Rev. 37, 689–694. https://doi.org/10.1080/01441647.2017.1340234

Pucher, J., Buehler, R., 2008. Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. Transp. Rev. 28, 495–528. https://doi.org/10.1080/01441640701806612

Qian, X., Niemeier, D., 2019. High impact prioritization of bikeshare program investment to improve disadvantaged communities' access to jobs and essential services. J. Transp. Geogr. 76, 52–70. https://doi.org/10.1016/j.jtrangeo.2019.02.008

Rodriguez-Valencia, A., Rosas-Satizábal, D., Gordo, D., Ochoa, A., 2019. Impact of household proximity to the cycling network on bicycle ridership: The case of Bogotá. J. Transp. Geogr. 79, 102480. https://doi.org/10.1016/j.jtrangeo.2019.102480

Rosas-Satizábal, D., Rodriguez-Valencia, A., 2019. Factors and policies explaining the emergence of the bicycle commuter in Bogotá. Case Stud. Transp. Policy 7, 138–149. https://doi.org/10.1016/j.cstp.2018.12.007

Rydin, Y., 2013. The future of planning: Beyond growth dependence. Policy Press.

Secretaría de Movilidad de Bogotá, 2019. Encuesta de Movilidad 2019, Informe de indicadores: encuesta de movilidad de Bogotá. Bogotá, Colombia.

Steinbach, R., Green, J., Datta, J., Edwards, P., 2011. Cycling and the city: a case study of how gendered, ethnic and class identities can shape healthy transport choices. Soc. Sci. Med. 72, 1123–30. https://doi.org/10.1016/j.socscimed.2011.01.033

Stępniak, M., Goliszek, S., 2017. Spatio-temporal variation of accessibility by public transport—the equity perspective, in: Ivan, I., Singleton, A., Horák, J., Inspektor, T. (Eds.), Lecture Notes in Geoinformation and Cartography. Springer, pp. 241–261. https://doi.org/10.1007/978-3-319-45123-7_18

Tennekes, M., 2018. Tmap: Thematic maps in R. J. Stat. Softw. 84. https://doi.org/10.18637/jss.v084.i06

Teunissen, T., Sarmiento, O., Zuidgeest, M., Brussel, M., 2015. Mapping Equality in Access: The Case of Bogotá's Sustainable Transportation Initiatives. Int. J. Sustain. Transp. 9, 457–467. https://doi.org/10.1080/15568318.2013.808388

Torres, A., Sarmiento, O.L., Stauber, C., Zarama, R., 2013. The ciclovia and cicloruta programs: Promising interventions to promote physical activity and social capital in bogotá, Colombia. Am. J. Public Health 103, e23–e30. https://doi.org/10.2105/AJPH.2012.301142

Valero-Mora, P.M., 2010. ggplot2: Elegant Graphics for Data Analysis , Second Edi. ed, Journal of Statistical Software. Springer. https://doi.org/10.18637/jss.v035.b01

Wickham, H., 2014. Tidy data. J. Stat. Softw. 59, 1–23. https://doi.org/10.18637/jss.v059.i10

Wickham, H., 2011. Ggplot2. Wiley Interdiscip. Rev. Comput. Stat. 3, 180–185. https://doi.org/10.1002/wics.147

Woodcock, J., Tainio, M., Cheshire, J., O'Brien, O., Goodman, A., 2014. Health effects of the London bicycle sharing system: Health impact modelling study. BMJ 348. https://doi.org/10.1136/bmj.g425

APPENDIX A

Trips faster cycling than by car by distances.

Distance (Km)	Total Trips by car	Trips faster by cycling					
		11.5 Km/h		13 Km/h		14.5 Km/h	
0.5	11649	11649	100%	11649	100%	11649	100%
1.0	48879	47264	97%	48879	100%	48879	100%
1.5	60383	53095	88%	58816	97%	60232	100%
2.0	71514	54830	77%	66644	93%	70739	99%
2.5	74917	44801	60%	64469	86%	71170	95%
3.0	76291	46585	61%	64661	85%	70943	93%
3.5	95657	49943	52%	65489	68%	76162	80%
4.0	65393	30865	47%	41586	64%	51979	79%
4.5	80923	29226	36%	54530	67%	66509	82%
5.0	86557	39332	45%	52821	61%	64785	75%
5.5	86380	24620	29%	47772	55%	70004	81%
6.0	85903	24078	28%	45767	53%	62404	73%
6.5	73604	19437	26%	39657	54%	50243	68%
7.0	62218	15990	26%	27261	44%	40860	66%
7.5	85861	15336	18%	45144	53%	58990	69%
8.0	70848	18175	26%	33990	48%	48128	68%
8.5	66083	15753	24%	29304	44%	39660	60%
9.0	47795	7820	16%	14981	31%	26669	56%
9.5	44235	8881	20%	15323	35%	26382	60%
10.0	43608	6263	14%	15101	35%	26833	62%
10.5	28124	2093	7%	9502	34%	13532	48%
11.0	33067	4579	14%	7900	24%	13309	40%
11.5	30266	2318	8%	4694	16%	13540	45%

12.0	18728	1041	6%	4139	22%	8254	44%
12.5	19054	1977	10%	5230	27%	9662	51%
13.0	21630	1253	6%	3896	18%	8134	38%
13.5	26547	588	2%	7045	27%	12051	45%
14.0	16758	0	0%	1809	11%	5398	32%
14.5	10202	0	0%	619	6%	3603	35%
15.0	8657	0	0%	748	9%	2960	34%
15.5	7949	0	0%	1022	13%	2027	25%
16.0	8999	37	0%	216	2%	1614	18%
16.5	9778	0	0%	0	0%	747	8%
17.0	7118	0	0%	114	2%	207	3%
17.5	6183	0	0%	0	0%	114	2%
18.0	2384	0	0%	0	0%	4	0%
18.5	3492	0	0%	0	0%	323	9%
19.0	5091	0	0%	0	0%	538	11%
19.5	5274	0	0%	0	0%	146	3%

Source: Own elaboration based on data from Bogotá’s HTS (2017)

APPENDIX B

Accessibility sensibility under different proportions of modal shifts.

Percentage of modal shift (car-to-bicycle)	Additional accessible opportunities		
	Low SES	Medium SES	High SES
5%	32610	30037	111994
10%	83420	79285	212346
15%	108963	144627	259163
20%	130118	252352	299539
25%	170972	316861	310492
30%	202331	468641	310492
35%	232418	622145	310492
40%	261952	763195	310492
45%	305233	896575	310492
50%	342603	1006531	310492
55%	367749	1101624	310492
60%	393728	1179799	310492
65%	434328	1265016	310492

70%	450222	1367923	310492
75%	466372	1429715	310492
80%	480208	1491663	310492
85%	497858	1526643	310492
90%	505773	1532647	310492
95%	513059	1551568	310492
100%	515283	1557676	310492

Source: Own elaboration based on data from Bogotá’s HTS (2017)s