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# Build it and give 'em bikes, and they will come: The effects of cycling infrastructure and bike-sharing system in Lisbon

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ABSTRACT

Reliable and detailed data are required for the evaluation of pro-bike investments. Longitudinal studies that compare the cycling levels before and after interventions provide crucial information to policy design. In cities where cycling is starting to grow, little data is available. The expansion of the cycling network and the implementation of a public e-bike sharing system were an opportunity to conduct a before-after evaluation of the effects of these two policies in cycling levels, in Lisbon, Portugal.

A "pen-and-paper" method for cyclists' manual counts was refined and tested. Data was collected from 2016 to 2018 in the city center, where significant changes to the built environment took place, as well as in an external control area. Four different types of locations were observed regarding the existence of cycling infrastructure and bike-sharing service. Besides flow, data included gender, helmet use, and bicycle type. The results revealed a 3.5-fold growth between 2016 and 2017 when the segregated cycling network was expanded in the city center, and an added 2.5-fold growth between 2017 and 2018, after the bike-sharing launching. City-wide, from 2017 to 2018, women's share increased from 16% to 22%, mostly driven by bike-sharing usage, while helmet use decreased from 45% to 30%. Bike-sharing accounted for 34% of all observed trips in 2018.

Our findings suggest that "hard" measures to encourage cycling, such as cycling networks and bike-sharing systems, can have considerable impacts on raising levels of bicycle modal share in a low cycling maturity city. Furthermore, the method allowed to distinguish cyclists using their bicycles from those using the bike-sharing system. Hence, we could isolate the effects of the two measures – provision of infrastructure and implementation of the bike-sharing system. The method proved to be a simple and effective way for city authorities and practitioners to collect detailed baseline and follow up data.

## 1. Introduction

Planners and policy-makers benefit from a greater understanding of available interventions for cycling promotion, and their relative effectiveness at different stages of cycling maturity of a city. In cities where cycling is starting to grow, little is known about who is cycling. How many people are cycling? For what purpose? Which routes are used? Commonly, in these cities, the attention of transportation agencies and mobility managers is not focused on this travel mode, so the tracking of cyclists is not a priority. The resulting lack of useful data is a problem because there is no basis upon which municipalities could potentially invest in effective cycling infrastructure. Given that these cities do not have historical experience with cycling, there is a need to understand and better inform city planners and players of what strategic infrastructure investments should be made and programs to deploy in order to leverage their cycling mode share and mature the cycling culture.

Although numerous studies point to infrastructure design, street patterns, destinations, traffic and population densities as critical factors associated with walking and cycling, they do not, however, prove that a change in any of those factors will lead to a change in walking and cycling (Krizek et al., 2009). The implementation and expansion of segregated cycling networks and facilities are interventions that have a high likelihood to successfully induce cycling (Buehler and Pucher, 2011; Dill and Carr, 2003; Pucher and Buehler, 2005; Santos et al., 2013), as tested before and after some interventions (Braun et al., 2016; Marqués et al., 2015). "If you build it, they will come" is a common expression used to justify the investment in cycling infrastructure when there are no spotted cyclists yet, suggesting that safe and comfortable infrastructure will provide the necessary conditions to the circulation of people that do not bicycle (yet) because they lack those conditions. It also suggests that it is a successful investment, although the literature is scarce on evidence that strictly relates new cycling infrastructure with

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an impact on the volume of cyclists, which results from an absence of practice of setting targets for interventions and monitor the outcomes.

The physical and built environment tends to influence and condition more the active modes, which may generate significant barriers and motivators for cycling. The perception of safety is perhaps one of the most important factors influencing the decision to bicycle, and cycling is often associated as risky and dangerous (Rissel et al., 2002). A number of studies have concentrated mainly on perceptions of risk in cycling and the provision of cycling facilities to overcome this barrier (for instance, Chataway et al., 2014; Götschi et al., 2018; McClintock and Cleary, 1996; Swiers et al., 2017; Vanparijs et al., 2015). Addressing both perceived and objective safety improvements require slightly different but necessarily coordinated approaches.

Another barrier is related to the physical effort of cycling. There is undoubtedly a relation between hilly cities and low cycling levels. Due to the physical effort involved, cyclists prefer level and moderate terrains over mountainous or steeper terrains (Stinson and Bhat, 2003; Winters et al., 2010), and do not associate cycling with a city with perceived hilliness. Perspiration, when arriving at work, is also considered as a significant deterrent to cycling adoption (Engbers and Hendriksen, 2010). Electric bicycles (E-bikes) require less physical effort, enabling more people to bicycle and more trips to be made by bicycle (Popovich et al., 2014), overcoming common barriers to bicycling for all types of riders (Dill and Rose, 2012).

Enabling active modes through basic infrastructure may be a necessary first step for many cities with little or no infrastructure, but such an approach is likely to have only modest impacts on travel behavior (Piatkowski et al., 2019). In another study, Dill & Voros (2007) found that objective measures of proximity to bike lanes were not associated with higher levels of cycling. However, positive perceptions of the availability of bike lanes were associated with more cycling and the desire to cycle more, and higher levels of street connectivity were associated with more cycling for utilitarian trips. The work of Piatkowski et al. (2019) further suggested that significant travel behavior changes may not be possible without policies and infrastructure levers that deter people from car driving, and that both enablers and deterrents, together, would be more efficient toward increasing active travel. Again, there is scarce evidence on how much these investments increase cycling levels (Pucher et al., 2010; Yang et al., 2010).

In the last decade, there has been an investment in bicycle infrastructures in several cities. However, there is an absence of official data collected by systematic observations to monitor the number of bicycle users or the impact of those investments, particularly in Portuguese cities where there is almost no reliable data. Barriers and motivators to cycling in Lisbon, our case-study city, are specially related with safety perceptions, lack of cycling infrastructure and facilities, and bicycle or e-bicycle ownership (Félix et al., 2019).

Bicycle sharing schemes are considered essential elements of urban transport policy and have spread rapidly (Morton, 2018). Nevertheless, evidence on bicycle mode share increases after the implementation of bike-sharing programs is sometimes confounded by improvements in bicycling facilities made at the same time (Pucher et al., 2010).

Lisbon's changes in the built environment, together with the expansion of a segregated cycling network, and the implementation of a bike-sharing system (with a 70% e-bike fleet) were an opportunity to assess the impact of these interventions in cycling adoption.

This study aims to provide a systematic before-after evaluation of the effects of these two policies on the volume of cyclists in Lisbon. This paper progresses by using a longitudinal 3-year observation dataset and a data collection method that allows differentiating bike-sharing users from private bicycle users. Findings from this case study can assist planners and policymakers to understand how these initiatives contribute to overcoming barriers to bicycle adoption when stepping out from a 'Starter' low-cycling maturity to a 'Climber' city, using PRESTO terminology (European Union's Intelligent Energy, 2010).

## 2. Lisbon case study

Lisbon is the Portuguese capital, with about half million inhabitants and an area of 100 km$^2$, although an estimated 2.8 million people live in the Lisbon Metropolitan Area (LMA), corresponding to about 27% of the population living in Portugal. From the LMA, a significant part of the population commutes to the capital city daily (nearly 30%).

The city is characterized by an irregular orography, with a historical center that includes the "seven hills" (with 110 m of maximum elevation), a plateau area in the Centre-North of the city, the Monsanto forest in the Westside with 228 m of peak elevation, and an 18 km-long riverside area along the Tagus River. Although being perceived as a hilly city, 54% of the streets are almost flat (< 3% inclination), while 75% are below a 5% grade, good enough for cycling (Félix, 2012). The city offers a highly fragmented bicycle network and a lack of places to safely store or lock a bike (Moura et al., 2017).

Although Lisbon's housing is not homogeneous, in some districts, it may be difficult to store a bicycle at home. For the ones that not have bicycle storage at home and thus are less likely to bicycle (Fernández-Heredia et al., 2016), bike-sharing systems can be a practical option. Furthermore, it is unusual to see bicycles parked outdoors at night due to the risk of theft, in contrast to cities with a higher bicycle modal share (Pucher and Buehler, 2008). The cycling modal share was 0.2% in 2011 (INE, 2011), far below the EU average of 8% (European Commission, 2014). The 2017 National Mobility Survey estimated that, in Lisbon, 0.6% of total daily trips are made by bicycle (INE, 2018). Lisbon' hills, the various types of pavement and the presence of tram rails, the behavior of car drivers, the sense of unsafe circulation and the inexistence of bicycle facilities to cycle or to safely store a bike, may explain the low rates of cycling.

Although there was no official data for a systematic observation and monitoring of the number of bicycle users in Lisbon prior to 2016, there was an investment in cycling infrastructure in several urban centers in the last decade, due to the perception that local actors have regarding the increase in the use of active modes of transport by the population. However, the planning of these infrastructures was not based on objective data of users and potential users. Such data would have provided better support for decision making at the municipal level, regarding the expansion and improvement of the cycling infrastructure, and respective support equipment and facilities.

The city has been adjusting to the timid growth of bicycle users, and the public authorities have been respondent to the cyclists' claims. The public transit – urban and suburban trains, ferries, buses, and metro – allowed the transport of bicycles, in somewhat restricted quantities and schedules, for some operators. Bicycle shops and small repair shops also appeared. Today, most high schools and universities already have bicycle parking facilities, which was not common before 2008. Some tentative bicycle promotion campaigns were made during the period of 2008–2012, such as the "Bike-to-Work Day" and the European mobility week, among others. In September of 2010, the city announced a program that foresaw the expansion of the cycling network to a total of 80 km, the adaptation of neighborhoods for traffic calming, and the introduction of a shared-use bicycle system during 2011 (the bike-sharing program was not implemented by then).

The number of cyclists has been visibly increasing in recent years, as the results from the national mobility survey suggest (0.6% in 2017); although we cannot compare this number with the census 2011 number, due to differences in the data collection methodology. Nevertheless, this growth of bicycle use can be assigned to those who live or work in the city. Part of this growth could be related to municipal investments in cycling infrastructures (mainly from 2008 to 2012), namely with the cycling network expansion, reaching 60 km in 2012, although highly fragmented – in fact, its planning and design aimed mostly recreational and not utilitarian trips – and parking areas for bicycles.

Lisbon's Central Business District (CBD) began a major urban and

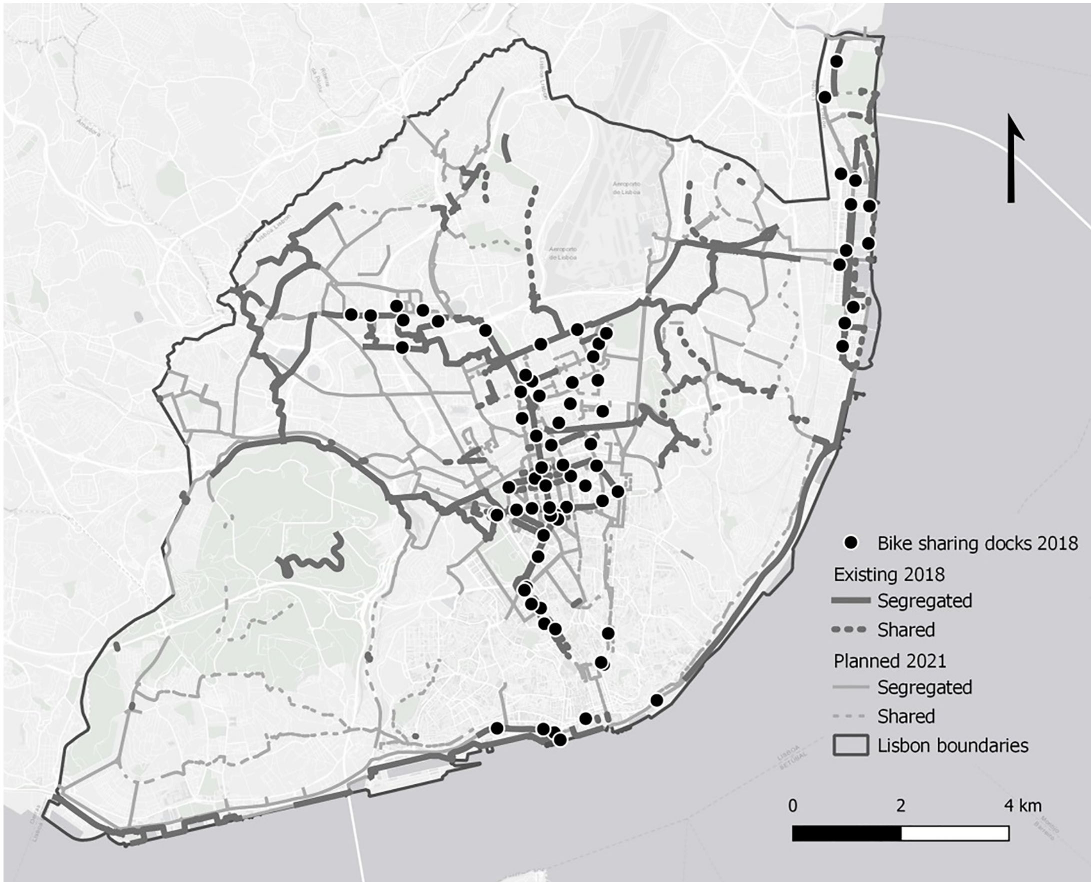


**Fig. 1.** Bike-sharing docks and cycling network expansion plan for Lisbon. *ESRI gray light basemap*.

mobility transformation in 2016, with road dieting measures to reduce main avenues' car capacity and driving speeds. Since 2016, recent municipal improvements included:

- The expansion and completion of a more comprehensive, connected, and commuting-oriented bicycle network, with 100 km of dedicated cycling infrastructure; and
- A bike-sharing system of 1 400 bicycles, with 70% of the fleet as e-bikes (pedelec), covering mainly the central business areas and the waterfront.

During the first year of operation, the bike-sharing system had a high demand, reaching about 7 trips/bicycle/day and more than one million trips made. The system was available at a relatively affordable annual fee of 25 euros (compared to the monthly public transport pass of 30 euros) and was subscribed by about 18,500 people (EMEL, 2018).

Fig. 1 illustrates the expansion plan of the cycling network, as well as the distribution of the bike-sharing stations. City efforts are being made for the cycling infrastructure to reach 200 km in 2021.

The city of Lisbon is not counting nor observing cyclists' activity, in a systematic way, except for one automatic counter installed at Av. Duque d'Ávila – an avenue in the city center – that meters the number and flow directions of cyclists on this segment of the segregated infrastructure. A finer and direct observation allowing to capture more detailed features of the cyclists, the trip and his/her vehicle, which cannot be captured by standard automatic counters, enables the municipality to better characterize and understand the requirements of the users of the bicycle infrastructure and better plan future investments that meet real needs and ensure a safer circulation for cyclists.

With the emerging technology of cyclists' data collection, such as laser, cameras, infrared cameras, or wi-fi networks detectors, it gets easier to collect data like flows of cyclists at a given spot. Also, bike-sharing or rental programs, and user-applications such as *Strava* or *Map my Ride*, collect precious data on routes, speeds, and profiles of cyclists that are not collected by the previous observation methods. Nevertheless, there are some disadvantages to these methods, as follows:

1. The equipment required to collect data, and its cost;
2. The possibility to collect data at simultaneous locations, when not having much equipment;
3. The data processing and analysis effort;
4. The availability of data from commercial companies and potential privacy issues;
5. The existing technics to collect data on the type of cyclist (e.g., gender, age, vehicle) does not have a reliable accuracy level yet and require much processing

In the context of a city that has plans for rapid improvements, installing equipment for data collection is less flexible, especially when the dynamics of the built environment are changing quickly. The observations of the cyclists' flows before installing a leg of a cycling infrastructure ought to be made prior to the intervention. The assessments prior and post interventions in the cycling network are a way of validation of such improvements and rely on a fast-implementation method.

## 3. Methods

### 3.1. Data collection

Data regarding before and after cycling levels were collected using manual counting methods on three occasions – 2016, 2017, and 2018.

Manual counting methods are relatively easier to set up compared to automated counting methods. Because the observer can move around, it is flexible to adapt and react to infrastructure planning. Moreover, several counting locations can be observed simultaneously for a lower cost than using automated counting systems. On the other hand, automated counting systems can collect data continuously and for extended periods of time. Also, automated counting can be considered to be less subjective than human observation. Manual counting relies on the person's observation skills, and different persons may have different appreciations.

However, human observation is capable of capturing, processing, and recording more diversified and detailed information and features of the cyclists when compared to video or machine processing. The potential for capturing a wider set of information is particularly noteworthy as other cycling attributes can provide additional behavioral insights that sheer numbers of cycling flows cannot provide.

Understanding who pedals at which locations can help manage and plan cycling network interventions and equipment. Indicators such as gender, age, wearing a helmet, or child seats, informs, for instance, the risk and safety levels of specific locations. Besides, evidence on the type of bicycle used in different areas, such as electric or folding bicycles, may also provide insights on city dynamics of housing conditions, transportation, or commuting distances.

In the scope of this research, we refined a "pen and paper" method for data collection. It is based on human observation of cyclists and was made yearly at different points simultaneously. The observers register flows, gender, age, helmet use, bicycle type, trip purpose, behavior, and other non-bicycle vehicles using the infrastructure.

This method presented several advantages. First, detailed information could be obtained regarding flows, cyclist characteristics, and bicycle (vehicle) types. Second, cyclists could be counted on and off the cycling infrastructure. Third, it does not depend on third-party technology providers. Nevertheless, as a straight-forward approach, it enabled fast data processing and instant profiling. On the other hand, the results are only as good as the observation skills of the person. In order to obtain reliable results, this method required training and field testing with the team of observers.

We applied the described method for collecting cycling data in 2017 and 2018. The 2016 baseline observations were drawn from existing datasets.

### 3.2. Baseline data – 2016

For the characterization of the baseline cycling data, we used an existing dataset of cycling volumes focused on the "Central Axis" area of Lisbon, which corresponds to the CDB, where significant cycling infrastructure improvements took place following a street improvement program. This area is characterized by a regular and orthogonal mesh, and a flat orography, favorable to bicycle circulation. Fig. 2 shows the existing cycling infrastructure in 2016 and 2017, in Lisbon. The majority of the 2017 cycling infrastructure expansion occurred in the "Central Axis" area.

The "Central Axis" improvement program was monitored in detail in other studies (Cambra et al., 2019) which collected data for pedestrian and cycling volumes. Cycling data was available for seven locations: three locations within the "Central Axis"; two locations in adjacent streets to the "Central Axis" and two locations in external streets to the study area, which were used as experimental controls. Data was collected using a screen line manual counting approach, which provided quantitative data on cyclist volumes.

### 3.3. Follow-up – 2017 and 2018

A more comprehensive data collection was made in 2017 and 2018. We fine-tuned the counting method while increasing the number of counting locations from 7 to 45, and also the spatial coverage (Fig. 3).

The observations were registered in a pre-formatted paper sheet that was filled by hand in each 15 min period. The following characteristics were registered for each observed cyclist:

- Cyclists (number), by flow direction;
- Gender (male/female);
- Helmet (yes/no);
- Age group (autonomous kid/adult/senior);
- Child transport (trailer, chair);
- Riding on the cycling infrastructure/on the road/on the sidewalk;
- Type of bicycle (folding/electric/shared/rental/cargo); and
- Type of trip (utilitarian/sport/leisure or tourism/deliveries).

The observations were made at intersections, in order to allow wider coverage of several axles, whenever possible. The criteria for selecting the 45 counting locations were as follows:

- Places where there has recently been a bicycle network intervention;
- Places where there will be a future intervention to the cycling network;
- Places on the existing cycle network; and
- Places where there is a perception that cyclists are riding, although they are not close to the existing cycle network (control area).

The 2017 observation campaign took place between May 29th and June 2nd (Monday to Friday). In 2018, the counting campaign occurred with the same methodology during the week of May 21st to 25th, with an extra counting day on June 5th. Sites were covered more than once each period, for data validation. The counting periods were chosen to match the Spring season when the probability of rain is very low, and during weeks that did not interfere with school vacation or holidays.

Since the current expansion of the cycling network was made mainly for commuting and utilitarian trips, we aimed to capture the flows of the commuting cyclists during the following counting periods:

- Morning peak period: between 8:00–10:00 am; and
- Afternoon peak period: between 5:00–7:00 pm.

Ten observers were trained and were responsible for five sites each, working for 4 h/day. The total amount of work for each observation campaign was about 400 counting hours, plus the preparation and data analysis, estimated in 150 h. We opt to share this indicator in order to support the planning of a similar approach in other cities and by other teams.

## 4. Results

### 4.1. Cyclist characterization attributes (2017 and 2018)

By using the refined manual count method, we were able to collect cyclist attributes in 2017 and 2018. A total of 6414 cyclists were counted in the 2017 observation campaign, during 20 peak hours spread over five days, representing an overall average of 1603 observed cyclists per peak hour in the city, or 35.63 cyclists per peak hour per location.

Overall, more male than female cyclists were observed, with a female share of about one-sixth (16%), below the average of other European cities that is one quarter (25%). 45% of the cyclists were wearing a helmet.

During this observation campaign, 515 folding bicycles were registered, representing 8% of the total number of bicycles observed. There were 80 electric bicycles (around 1%) registered in this campaign, although it is not possible to find a pattern of their spatial

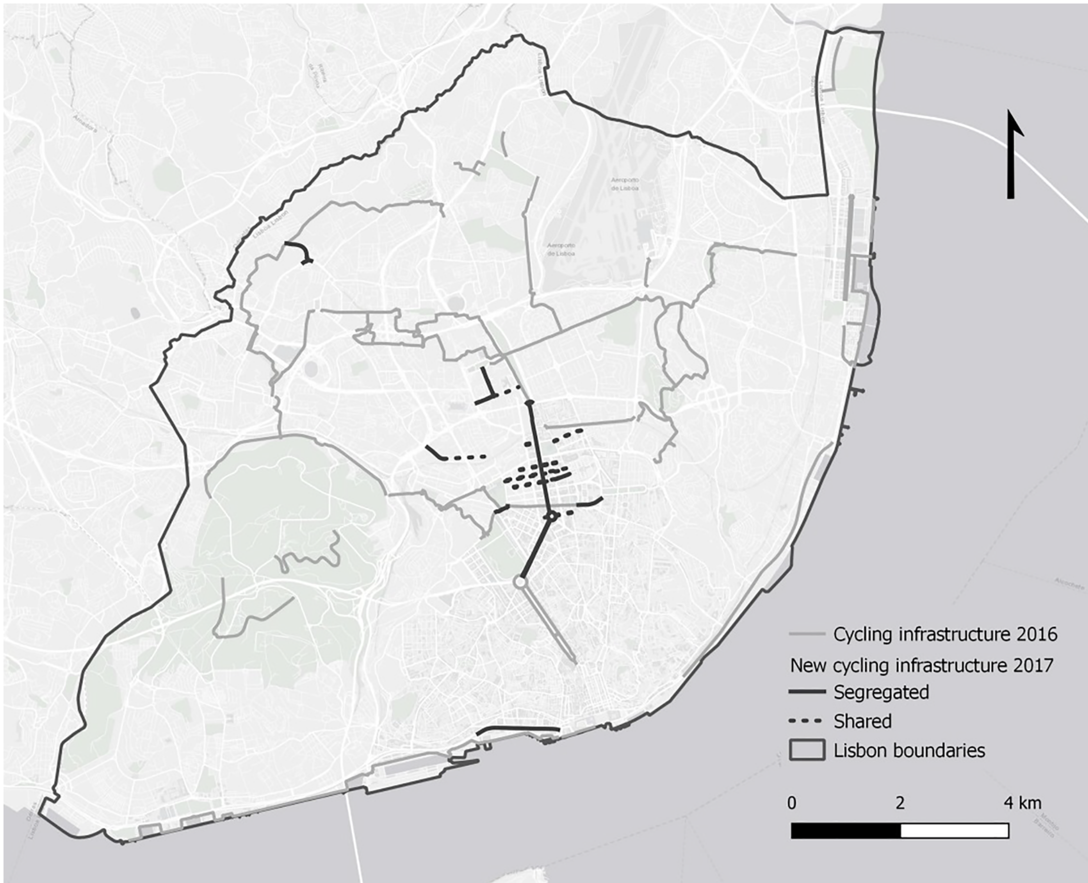


**Fig. 2.** Existing and new cycling infrastructure by 2016 and 2017. *ESRI gray light basemap.*

distribution. A total of 175 bicycle trips with a child seat or trailer were recorded, which is equivalent to 3% of the total number of observations. It is noteworthy to observe that most of this bicycling equipment was observed in the "Central Axis" area, where the existing segregated cycling infrastructure provides higher safety.

Likewise, a total of 11,491 cyclists were counted in 2018, also during 20 peak hours spread over five days, representing an overall average of 2872 registered cyclists per peak hour in the city, 63.84 per peak hour per location.

Overall, more male than female cyclists were observed, with a proportion of one fifth (22%), which is closer to the European average. 30% of the cyclists were observed wearing a helmet, which is lower than the previous counting period.

During this observation campaign, 930 folding bicycles were registered, representing 12% of the total number of bicycles observed. A total of 225 bicycle trips with a child seat or trailer were recorded, which is the same percentage of non-shared bicycles registered in 2017. The bike-sharing bicycles accounted for 34% of the observed vehicles.

Table 1 presents the aggregated results per year of observation campaign, for the 45 observation points during the 20 peak hours.

Comparing the observations from 2017 to 2018, we observed:

- An overall increase of cyclists' volume of almost twice as much;
- An overall increase of the women shares, from 16 to 22%;
- A decrease in the bicycle helmet wearing, from 45 to 30%;
- More than twice folding bicycles were counted in 2018, and more bicycles with a child seat or trailer, in absolute terms;
- Shared bicycles accounted for 34% of observations in 2018. The system did not exist in 2017 at the time of the observation campaign.

### *4.2. Before-After cycling volumes – cycling network expansion and bike-sharing system implementation*

Based on the manual observations carried out by the Instituto Superior Técnico in July 2016 (Cambra et al., 2019), we compared the corresponding 7 counting locations and equivalent periods of time with 2017 and 2018 observations. These locations can be grouped into three areas, as shown below in Table 2. Fig. 4 shows the location of the seven observation points with data from 2016, in relation to existing and improved cycling infrastructure (see Table 3).

From the comparison of 2016 with 2017 data, we conclude that:

- The volume of cyclists increased 4 to 7 times in the "Central Axis" area (pre- and post-bicycle infrastructure);
- The volume of cyclists, which in 2016 was higher in the location D (with an existing segregated bicycle track), did not increase significantly in 2017;
- The volume of cyclists was higher in 2017 in the "Central Axis" area (sites A, B, and C), where the interventions improved dramatically the attractiveness of the cycling infrastructure;
- The volume of cyclists decreased in location E, a street with lower traffic speeds, but with no cycling infrastructure. The parallel "Central Axis" became a better alternative for cycling;
- The volume of cyclists increased only slightly where the cycling network did not expand (i.e., experimental control area, locations F, and G).

Grouping the locations with similar characteristics regarding the built environment and bike-sharing availability, it is possible to assess the impacts of the two policies and summarize the previous considerations as shown in Table 4.


**Fig. 3.** Location of the 45 observation points, and the existing and new cycling infrastructure by 2016 and 2017. *ESRI gray light basemap.*

Regarding location F (Av. Almirante Reis), we note that this street has two bike-sharing stations, North and South from the observation point, but still separated by 2 km apart from each other. Nevertheless, bike-sharing cyclists' volumes were low, in the 2018 campaign, suggesting that such policy might not have an impact on rising cycling levels if the street does not include a safe cycling infrastructure, even where there is access to shared bicycles (or e-bikes).

## 5. Discussion

This article describes a case study in Lisbon where the implementation of two cycling policies, evolving "hard" measures, occurred sequentially within 3 years. Cycling volumes were counted in 2016 (our time reference for comparison), in 7 locations, before a significant expansion of the cycling infrastructure (i.e., the first hard measure), which occurred in 2017; and, after the implementation of a shared bike system (in 2018) (i.e., the second hard measure). Additionally, a manual counting method was fine-tuned, enabling the collection of cyclists' attributes and the observation of the corresponding trends (2017/2018) in 45 locations.

There was a strong and significant increase in the cycling volume, from 2016 to 2017, in locations where infrastructure was improved. Likewise, there was also a strong and significant increase in the cycling volume from 2017 to 2018, in the locations served by the bike-sharing system.

In locations A, B, C, and D, corresponding to the central area of the city with both cycling infrastructure and bike-sharing, it was possible to detect a four-fold increase (+302%) of bicycle users between the expansion of the cycling network, and an additional 2.5-fold increase (+165%) after the implementation of a bicycle-sharing system (see Fig. 5). From 2016 to 2018, cyclists' volume increased almost ten times in this area (+965%).

On another hand, the volume of cyclists in the control area (locations E and F) increased only slightly, in relative terms, when compared to 2016 (refer to the right side of Fig. 5). Still, there was a significant volume of cyclists in this area, in places without a cycling network, which can be associated with a systemic increase in cycling levels in the city of Lisbon. Again, the decreasing number of cyclists observed in Av. Cinco de Outubro (location E) confirms that this segment was no longer the best route for the North-South flows, when the parallel Av. da República (location A) became a better alternative for cycling with a segregated infrastructure.

The ramp-up effect of the cycling network expansion might have also been captured in 2018 and should not be ignored. This effect might

**Table 1**
Aggregated data collected in each observation campaign.

| Campaign | Cyclists | Cyc./h | Cyc./h/location | Female (%) | Helmet (%) | Folding (%) | Child seat (%) | Bike-Sharing (%) |
|---|---|---|---|---|---|---|---|---|
| 2017 | 6 414 | 1 603 | 35.63 | 15.68 | 45.33 | 8.03 | 2.73 | – |
| 2018 | 11 491 | 2 872 | 63.84 | 21.57 | 30.16 | 12.27 | 2.97 | 34.04 |
| Difference | 79% | | | 5.89 | −15.17 | 4.24 | 0.24 | 34.04 |

**Table 2**
Areas and corresponding comparable locations for observations of cyclists between 2016, 2017, and 2018.

| Area | Local | Streets or segments | Notes |
|---|---|---|---|
| "Central Axis" | A | Av. da República | New segregated cycling infrastructure (bi-directional) |
| | B | Av. da República/Campo Pequeno | New segregated cycling infrastructure (bi-directional) |
| | C | Av. Fontes Pereira de Melo/Picoas | New segregated cycling infrastructure (uni-directional) |
| Adjacent area to the "Central Axis" | D | Av. Duque d'Ávila | Segregated cycling infrastructure before recent interventions |
| | E | Av. Cinco de Outubro | Parallel to Av. República, with lower traffic speed |
| Control area | F | Av. Almirante Reis | Important Lisbon artery |
| | G | Rua Morais Soares | Adjacent to Av. Almirante Reis |

impact not only the observation locations but also as an overall effect on the city cycling levels. Although the improvements on the cycling network were not made at the same time as the implementation of a bike-sharing program, we should be aware that evidence on cycling increases after the implementation of the bike-sharing system can be sometimes confounded with improvements in the bicycling facilities made at the same time, as suggested in previous research (Pucher et al., 2010).

We highlight that the type of cycling infrastructure under scrutiny was mostly a segregated bicycle lane, mainly at the sidewalk level and where cyclists only have contact with other road users at intersections (Fig. 6).

This type of cycling infrastructure is known to be safer than physically non-segregated bike lanes, though also many criticize building the cycling infrastructure at the sidewalk level (which might potentially generate conflicts with pedestrians) and bi-directional lanes (which conflicts with car drivers at intersections). Nevertheless, the implemented bicycle infrastructure provides a safer environment, in particular for more risk-averse persons, that otherwise would not bicycle. A segregated bicycle lane serves any bicycle user, being more inclusive, and is therefore expected to attract more people to experience cycling.

2018 observations indicate that more female cyclists were counted in locations with cycling infrastructure and bike-sharing stations ($M = 21.71\%$ vs. $M = 16.36\%$, according to Welch's *t*-test, $t(33.93) = 3.78$, $p < .001$) (Fig. 7), while a lower percentage of cyclists wearing a helmet were observed at the same locations ($M = 29.46\%$ vs. $M = 38.71\%$, according to Welch's *t*-test, $t(38.82) = -3.43$, $p < .001$) (Fig. 8), which may sustain this conclusion regarding risk-averse persons, as discussed by several authors (Garrard et al., 2012, 2008; Sustrans, 2018). In another hand, bike-sharing users are less likely to carry and wear a helmet (Basch et al., 2014; Fischer et al., 2012). Data regarding autonomous kids cycling and child seats were not enough to reach solid conclusions.

A second caveat should be made regarding the type of bicycles in Lisbon's bike-sharing system fleet, which has 70% of e-bikes (pedelec).

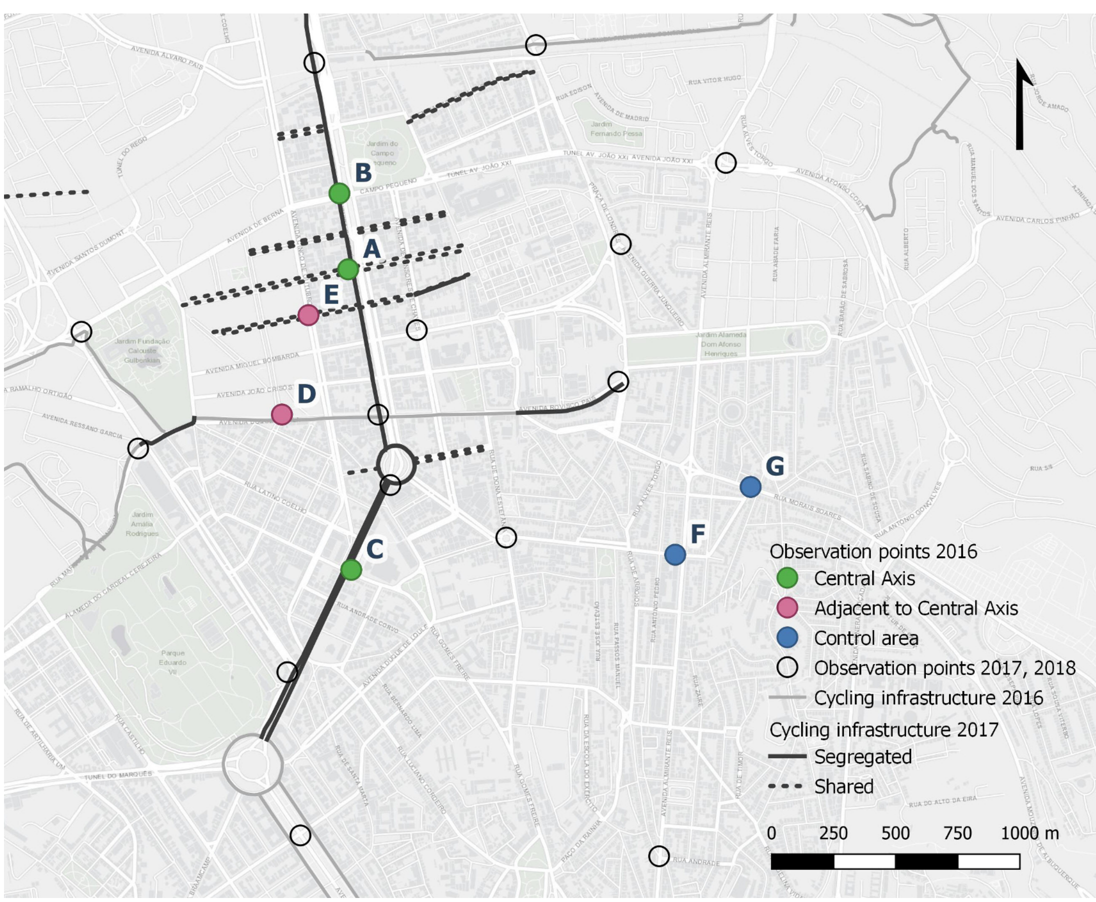


**Fig. 4.** Location of the 2016 observation points. *ESRI gray light basemap.*

**Table 3**
Volume of cyclists per hour (during the four peak hours), by location and year of observation.

| Local | 2016 | | | 2017 | | | 2018 | | | Variation | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Own bicycle | Bike sharing | Total | Own bicycle | Bike sharing | Total | Own bicycle | Bike sharing | Total | 2016–2017 | 2017–2018 |
| A | 9.0 | – | 9.0 | 48.5 | – | 48.5 | 62.5 | 73.5 | 136.0 | 439% | 180% |
| B | 5.9 | – | 5.9 | 51.8 | – | 51.8 | 55.3 | 66.3 | 121.5 | 785% | 135% |
| C | 3.9 | – | 3.9 | 27.8 | – | 27.8 | 34.5 | 33.0 | 67.5 | 612% | 143% |
| D | 17.6 | – | 17.6 | 18.3 | – | 18.3 | 36.5 | 25.8 | 62.3 | 4% | 241% |
| E | 6.1 | – | 6.1 | 4.3 | – | 4.3 | 1.5 | 0.8 | 2.3 | −31% | −47% |
| F | 6.3 | – | 6.3 | 8.3 | – | 8.3 | 11.5 | 0.8 | 12.3 | 32% | 48% |
| G | 8.0 | – | 8.0 | 7.3 | – | 7.3 | 11.8 | 0.0 | 11.8 | −9% | 62% |

**Table 4**
Summary of the impacts of each policy at four different groups of locations.

| Local | Situation | 2016–2017 | 2017–2018 |
|---|---|---|---|
| ***Cycling infrastructure*** | | | |
| A, B, C | New | + + | + |
| D | Existing | 0 | + + |
| E | None | – | – |
| F, G | None | 0 | + |
| ***Bike-sharing system*** | | | |
| A, B, C | Served | n.a. | + + |
| D | Served | | + + |
| E | Served | | 0 |
| F, G | Not Served | | 0 |

Notes: '+ +' huge positive impact; '+' positive impact; '0' no impact; '−' negative impact; 'n.a.' not applicable.

Many people believe the city is too hilly to bicycle, even when their trips are done mostly in flat – or almost flat – areas. When having access to an e-bike, these users may overcome the perceived barriers of distance, trip duration, effort, hills, and the risk of arriving sweaty to destinations, which is particularly relevant in a city like Lisbon. Besides, it is more "trendy" to use a vehicle with more technology such as an e-bike, in contrast to the simplicity of a conventional bicycle. Electric bicycle fleets are uncommon generally but are becoming more common in municipal bike-sharing systems. The results suggest that a bike-sharing system increases cycling levels, although we cannot conclude that a bike-sharing system with only conventional bicycles would not result in similar impacts. In this case, we observed that the bike-sharing system was responsible for the largest share of the growth in the volume of cyclists (79%) in 2018 when compared to the volume registered in 2017.

Cycling levels have been reported to increase following infrastructure improvements in various studies (see for instance Forsyth and Krizek, 2010, Pucher et al., 2010), either by increasing overall time spent cycling (Panter et al., 2016) or attracting new users (Goodman et al., 2013). However, few existing studies have reported on cycling volume change following infrastructure improvement. One of the reasons may be related to the difficulty of collecting baseline data before the implementation of cycling projects. The lack of baseline data to compare against still stands as a challenge for researchers and policy-makers to evaluate the effectiveness of cycling interventions (Krizek et al., 2009). Despite the development of technological solutions to count cyclists over longer periods, these systems lack the flexibility to be placed in the intervention sites within short notice.

The method used in this study, a refined "pen and paper" manual counting approach, provided a cost-effective solution to collect baseline and follow up data. In addition, this approach permitted to characterize cyclists and bicycles via several qualitative attributes that are usually not recorded by automated counters. In particular, the characterization of the bicycles, distinguishing private bicycles from shared bicycles,

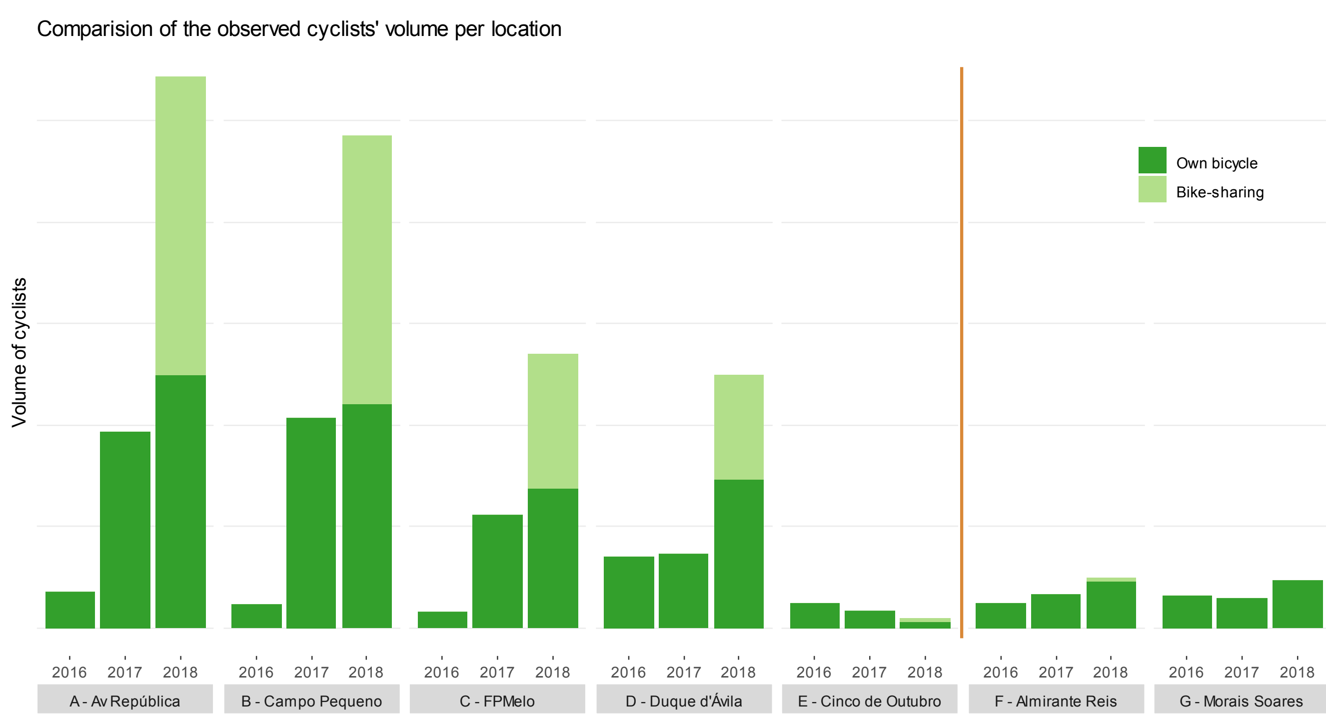


**Fig. 5.** Comparison of the volume of observed cyclists by location in 2016, 2017, and 2018. On the left side of the vertical line: the "Central Axis" and adjacent locations; on the right side: the control area locations.

**Fig. 6.** Segregated bicycle infrastructure at the sidewalk level, uni and bi-directional, respectively, in central Lisbon (photo credits: *Sexta de Bicicleta – MUBi*).


**Fig. 7.** Share of women at each observation point. *ESRI grey light basemap*.

provided evidence on the effects of the implementation of the bike-sharing system. As noted by Pucher et al. (2010), the interpretation of these results requires some caution due to a confounding effect of different complementary interventions as the provision of infrastructure and shared bike systems.

Our evidence suggests that a synergy exists between these two pro-bicycle programs. In our case study, we found places where there were bike-sharing stations available but no dedicated cycling infrastructure. In these cases, there was not a significant increase in the cycling volume. These findings corroborate the necessity to overcome the barriers associated with safety perception, stated in similar studies (Félix et al., 2019; Fowler et al., 2017; Muñoz et al., 2016), as a pre-requisite to increasing cycling levels.

## 6. Conclusions

Interventions to promote cycling still lack evidence on their effectiveness. Longitudinal data collection is required to compare before and after cycling behavior. Adding to quantitative cycling volumes, qualitative attributes can contribute to understanding the effects of bicycle promotion policies better. The refined “pen and paper” data collection method presented in this paper proved to be reliable, adaptive to planning processes of infrastructure and equipment, affordable, and easy to be replicated in different cities. It allows understanding where people bicycle and who they are.

Recent municipal investments in cycling infrastructure and equipment were an opportunity to assess how “hard” cycling promotion


**Fig. 8.** Share of helmet use at each observation point. *ESRI grey light basemap*.

policies can impact cycling levels in low cycling maturity cities. From observations prior and post interventions that aimed to encourage cycling, we verified a 3.5-fold increase of the cyclists' volume in the city center after the cycling network expansion and an additional 2.5-fold after the launching of a bike-sharing system. In the city center, the cyclists' volume increased 817% after both interventions, from 2016 to 2018. The method allowed to assess the effects of each policy separately and combined, by distinguishing bike-sharing cyclists from the others.

The results suggest that such interventions are a game-changer to start the process of a city's progression towards higher cycling maturity levels, especially if they are implemented in a city with almost no cycling modal share, such as our case study. The results of the present case are comparable with other case-studies, where similar interventions occurred at the same stage of cycling maturity.

## CRediT authorship contribution statement

**Rosa Félix:** Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft. **Paulo Cambra:** Writing - review & editing. **Filipe Moura:** Supervision, Project administration, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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