

BIKE SHARING SYSTEMS DURING DISRUPTIVE PUBLIC HEALTH CRISES: THE CASE OF LISBON'S *GIRA*

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Submitted to the Faculty of Engineering of the University of Porto, in partial fulfilment of
the requirements for the degree of

PhD in Spatial Planning

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APRIL, 2023

DOCTORAL PROGRAM IN SPATIAL PLANNING 2022/2023

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This document was produced from an electronic version provided by the respective Author.

PhD scholarship PD/BD/146494/2019 granted by the Portuguese Foundation for Science and Technology (FCT).



UNIÃO EUROPEIA
Fundo Social Europeu

To Isabel, to my brother and to my parents

“What if we fail to stop the erosion of cities by automobiles? What if we are prevented from catalyzing workable and vital cities because the practical steps needed to do so are in conflict with the practical steps demanded by erosion? There is a silver lining to everything. In that case we Americans will hardly need to ponder a mystery that has troubled men for millennia: What is the purpose of life? For us, the answer will be clear, established and for all practical purposes indisputable: The purpose of life is to produce and consume automobiles.”

Jane Jacobs, in The Death and Life of Great American Cities

ACKNOWLEDGMENTS

I would first like to thank my supervisor, Professor Cecília Silva, not only for accepting to supervise me throughout my PhD but for all the support and time spent helping me in the development of this thesis. I would also like to thank my co-supervisor, Professor Frederico Moura e Sá from the University of Aveiro, for his availability as well as the helpful insights from his experience with implementing bike sharing systems.

Thanks to all my colleagues from CITTA, especially Ana Proença and Isabel Cunha who began their PhDs at the same time as mine (our meetings for sharing our frustrations were especially helpful in maintaining my sanity). Thanks to Miguel Lopes (the co-author of my first published paper during this PhD, written during the first months of the COVID-19 lockdown when we needed to distract our minds), Marcelo Altieri and Catarina Cadima for their help regarding the quantitative methods employed in this PhD. I also thank my colleagues from the Science at Lunch Sessions for listening to my several presentations on bike sharing and COVID-19 and for all the helpful comments to improve those studies. I thank Professor Filipe Moura for allowing me to attend his TDM classes, whose introduction to statistical methods was fundamental for the development of this thesis. I would also like to thank the several anonymous reviewers whose insightful and constructive criticism helped to significantly improve several of the papers that constitute this PhD. I also acknowledge the support of the Portuguese Foundation for Science and Technology (FCT) for investing in my PhD through the scholarship PD/BD/146494/2019.

Last but not least, a special thanks to my family for all the support along this journey, especially my girlfriend as well as my brother for being always available to listen and endure my several takes when practising my presentations and for serving as test-subjects for my survey and interviews (your sacrifice is appreciated).

ABSTRACT

As a consequence of the several negative externalities associated with private car usage, including its contribution to climate change, there is a growing pressure to promote a more sustainable mobility through supporting alternative modes of transport. Simultaneously, the coronavirus pandemic has revealed the fragility of current transport systems in ensuring the mobility needs of citizens during disruptive events. Particularly worrying, the coronavirus has exacerbated the dependency on car usage, by especially affecting one of the major alternatives to the car: Public Transport (PT). With COVID-19 still impacting the normal function of societies, coupled with an increase in the likelihood of more frequent and severe epidemics in the future, improving the resilience of transport systems to disruptions while ensuring their sustainability has become an important challenge. Due to its efficiency and versatility, the bicycle has positioned itself as one of the most promising urban transport solutions during disruptive events. This thesis focuses on one of the most popular policies promoting cycling: bike sharing systems (BSS), which have witnessed a meteoric rise in the last decade. With more and more cities looking at bike sharing as a possible path to improve the sustainability and resilience of their transport systems, is it increasingly important to clarify the role that BSS can play in achieving this goal.

Thus, the main goal of this thesis-by-publication was to assess the potential role of bike sharing towards increasing the sustainability and the resilience of urban transport systems during disruptive public health crises such as the current coronavirus pandemic. Using as case-study the BSS of Lisbon (entitled *GIRA*), this thesis has resorted to an explanatory sequential mixed methods design, where the quantitative approaches were complemented by qualitative methods. The quantitative phase consisted of a cross-sectional travel survey, aimed at assessing the main impacts of COVID-19 on the travel behaviour (including modal shift dynamics, frequency and purpose for using BSS) and motivations of *GIRA* users. The qualitative phase consisted of employing semi-structured interviews to explore in more depth the most significant COVID-19 impacts identified in the travel survey. Statistical analyses were applied to the results of the travel survey (including non-parametric group comparison tests, factor analyses, ANOVAs and multinomial logit models), while the data obtained from the semi-structured interviews was analysed through the use of thematic analysis.

This research establishes that bike sharing can increase the resilience of urban transport systems during disruptive events like COVID-19 by providing a transport alternative to the most affected modes, with a significant increase in the importance of using BSS to avoid PT and for social distancing. Furthermore, even during the coronavirus lockdowns, users still turned to BSS to fulfil their mobility needs. Significant changes in the relationship of BSS with other modes of transport have been found as well, with COVID-19 accentuating the relationship of competitiveness between BSS and PT. In addition, BSS users associated several other advantages of bike sharing, including not only tangible benefits like reductions in travels times and costs, but more intangible ones such as the pleasure of cycling or its perceived environmental and health gains, contrasting with the stressful experiences of driving or using PT. Moreover, four major factors affecting the competitiveness of bike sharing as a mode of transport were identified. Ensuring that bike sharing covers the major destinations of users and that there is a good distribution of shared bicycles is vital for its users to rely on BSS for their travel needs, while directly influencing the travel time competitiveness of bike sharing. Likewise, shared e-bikes were highly regarded by BSS users as they solve some of the main barriers for cycling namely physical effort. Lastly, the perceived safety of using bike sharing is a major barrier, which now encompasses two different dimensions: perceived dangerous traffic conditions and (less importantly) the risk of infection posed by the coronavirus. Findings also suggest that policies focused on cost savings could be relevant to induce further car modal shifts to BSS as reductions in travel costs were found to be especially important to users replacing car trips.

KEYWORDS: Bike sharing; COVID-19; Impacts; Resilience; Sustainable mobility; Urban mobility; Policy responses; Modal shift dynamics; Public transport; Car use; Motivations; Safety perceptions; Travel survey; Semi-structured interviews.

RESUMO

Como consequência das várias externalidades negativas associadas à utilização excessiva do automóvel, incluindo o seu contributo negativo para as alterações climáticas, existe uma pressão crescente para incentivar uma mobilidade mais sustentável através da promoção de modos alternativos. Paralelamente, a pandemia da COVID-19 revelou a fragilidade dos atuais sistemas de transporte em assegurar as necessidades de mobilidade da população durante eventos disruptivos. Particularmente preocupante, a pandemia exacerbou a dependência do uso do automóvel ao prejudicar especialmente uma das principais alternativas: o Transporte Público (TP). Com a COVID-19 ainda a condicionar o funcionamento normal das sociedades, juntamente com o risco crescente de ocorrência de novas epidemias no futuro, importa aumentar a resiliência dos sistemas de transporte, ao mesmo tempo que se garante a sua sustentabilidade. Devido à sua eficiência e versatilidade, a bicicleta tem-se posicionado como uma das soluções de mobilidade urbana mais promissoras durante eventos disruptivos. Esta tese foca-se numa das políticas mais disseminadas de promoção da bicicleta: os sistemas de bicicletas partilhadas (SBP). Com o aumento da popularidade dos SBP dentro das cidades, reveste-se de uma importância acrescida esclarecer o papel que os SBP podem desempenhar na melhoria da sustentabilidade e resiliência dos seus sistemas de transporte.

Consequentemente, o principal objetivo desta tese-por-articles consistiu em avaliar o potencial papel das bicicletas partilhadas no aumento da sustentabilidade e resiliência dos sistemas de transporte urbanos durante crises disruptivas de saúde pública, como a atual pandemia do coronavírus. Utilizando como caso de estudo o SBP de Lisboa (intitulado *GIRA*), esta tese recorreu à utilização de métodos mistos através de uma abordagem sequencial, em que os métodos quantitativos foram complementados por métodos qualitativos. A fase quantitativa consistiu na aplicação de um inquérito à mobilidade, com o objetivo de avaliar os principais impactos da COVID-19 no comportamento de viagem (incluindo dinâmicas modais, frequência e propósito de utilização do SBP) e nas motivações dos utilizadores da *GIRA*. A fase qualitativa consistiu na utilização de entrevistas semiestruturadas tendo como intuito detalhar os impactos da COVID-19 identificados como mais significativos durante o inquérito. Aplicaram-se análises estatísticas aos resultados do inquérito (incluindo testes não paramétricos de comparação de grupos, análises fatoriais, ANOVAs e modelos logit multinomiais), enquanto que os dados das entrevistas foram alvo de uma análise temática.

Esta investigação demonstra que os SBP podem aumentar a resiliência dos sistemas de transporte urbanos durante eventos disruptivos como a COVID-19 ao providenciarem uma alternativa aos modos mais afetados, revelando-se como uma forma de evitar o TP e de manter uma distância social. Além disso, mesmo durante os períodos de confinamento, os utilizadores continuaram a recorrer aos SBP para as suas necessidades de mobilidade. Foram também encontradas alterações significativas na relação entre os SBP e outros modos de transporte, com a COVID-19 a acentuar a relação de competitividade entre os SBP e o TP. Adicionalmente, os utilizadores de SBP associaram diversas vantagens adicionais às bicicletas partilhadas, incluindo não só benefícios tangíveis, como reduções nos tempos e custos de viagem, mas também intangíveis, como o prazer de andar de bicicleta ou os benefícios ambientais e de saúde, em contraste com as experiências de stress associadas ao uso do automóvel ou do TP. Paralelamente, foram identificados quatro grandes fatores que afetam a competitividade dos SBP enquanto modo de transporte. Assegurar que os SBP cobrem os principais destinos e que exista uma boa distribuição das bicicletas partilhadas é vital para a confiança dos utilizadores nos SBP, influenciando diretamente os seus tempos de viagem. Da mesma forma, a existência de bicicletas elétricas foi altamente apreciada pelos utilizadores de SBP, já que permite ultrapassar algumas das principais barreiras para o uso da bicicleta, nomeadamente o esforço físico. Por fim, a segurança percebida de utilizar uma bicicleta partilhada é uma forte barreira, contendo duas dimensões diferentes: a percepção

de condições de tráfego perigosas e (menos importante) o risco de infeção representado pelo coronavírus. Este estudo sugere, também, que políticas focadas nos custos de transporte podem ser particularmente eficazes na indução de uma maior mudança modal do automóvel para os SBP, já que reduções nos custos de viagem foram especialmente importantes para os utilizadores que substituem viagens de automóvel.

PALAVRAS-CHAVE: Bicicletas partilhadas; COVID-19; Impactos; Resiliência; Mobilidade sustentável; Mobilidade urbana; Respostas políticas; Dinâmicas modais; Transporte público; Uso do automóvel; Motivações; Perceções de segurança; Inquérito à mobilidade; Entrevistas semiestruturadas.

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

AIC – Akaike Information Criterion

AML – *Área Metropolitana de Lisboa* (Lisbon Metropolitan Area)

ANOVA – Analysis of variance

BSS – Bike sharing system(s)

CDC – Center for Disease Control and Prevention

CH₄ – Methane

CI – Confidence interval

CO₂ – Carbon dioxide

COVID-19 – Coronavirus disease 2019

EFA – Exploratory factor analysis

EU – European Union

F-gases – Fluorinated gases

GHG – Greenhouse gas(es)

GDPR – General Data Protection Regulation

GPS – Global Positioning System

ICT – Information and communications technologies

IGOs – Intergovernmental organizations

INE – *Instituto Nacional de Estatística* (Portuguese National Institute of Statistics)

IPCC – Intergovernmental Panel on Climate Change

KMO – Kaiser-Meyer-Olkin

LCA – Life-cycle analysis

LL – Log likelihood

LR – Likelihood ratio test

MNL – Multinomial logit

N₂O – Nitrous oxide

NO_x – Nitrogen oxides

O/D – Origin-Destination

OECD – Organisation for Economic Co-operation and Development

OR – Odds ratio

PA – Physical activity

PCA – Principal Component Analysis

PM – Particulate matter

POI – Points-of-interest

PT – Public transport

RQ – Research question

SBP – *Sistema(s) de bicicletas partilhadas* (bike sharing system(s))

SP – Stated preference

TP – *Transporte público* (public transport)

TRID – Transport Research International Documentation

UK – United Kingdom

USA – United States of America

VMT – Vehicle miles travelled

WEBs – Wider economic benefits

WoS – Web of Science

WHO – World Health Organization

1.

INTRODUCTION

1.1. FRAMING

The latest reports on climate change¹ are clear: to limit the increase in global warming to 1.5°C above pre-industrial levels, urgent action is needed in the next few years. Failing to halt this rise in global temperatures will have devastating consequences for society (IPCC, 2018, 2022; Lenton *et al.*, 2019).

The sector with the fastest growing rates of CO₂ emissions (the main contributor to climate change) is the transport sector with emissions increasing at a rate of 2.5% per year (Rogelj *et al.*, 2018). At the same time it is the least diversified energy end-use sector with 92% of transport energy demand consisting of oil products (Rogelj *et al.*, 2018). The transport sector is already responsible for 23% of global energy-related CO₂ emissions, of which almost three-quarters are generated by road transport with car travel being the main source (Graham-Rowe *et al.*, 2011). For instance, in the European Union (EU), transport is the only sector in which CO₂ emissions continue to increase (EC, 2016), with light duty vehicles (cars and vans) already accounting for 15% of all CO₂ emissions (EC, 2020).

Besides the impact on climate change, the transport sector has several other environmental impacts. It is amongst the main air pollution sources, with road transport being responsible for up to 30% of all particulate matter (PM) emissions in Europe, and up to 50% of PM in OECD mostly because of diesel motor vehicles (WHO, 2016a). Transport is likewise a significant contributor to the formation of ground-level ozone and smog (WHO, 2016a; Rodrigue, 2020). Additionally, road traffic is the biggest source of noise pollution in cities, with air and rail traffic as well having significant impacts (WHO, 2016b). Transport also has substantial negative effects on freshwater quality, biodiversity and land use (Rodrigue, 2020).

Other major impact of road traffic often overlooked is the number of deaths and injuries related to traffic crashes. In fact, according to the WHO, road traffic crashes are the 8th leading cause of death globally, being the number one cause of death for people aged between 5 and 29 years. In 2016, 1.35 million people died from road traffic crashes, with the number of injuries estimated in the tens of millions (WHO, 2018). For example, in Portugal 629 people died (the equivalent of three A320 airplanes crashing) and 2 168 suffered serious injuries in road traffic crashes in 2019 alone, costing the country 1.6% of its GDP in economic and social losses (ANSR, 2019).

The overreliance on car travel is the main cause for these negative impacts, which also has repercussions on the economy with, for instance, congestion costing nearly 100 billion € annually in the EU alone (EC, 2019). Furthermore, the significant costs of building the infrastructure needed to support car usage, such as roads and car parking, are typically externalized, resulting in increases on developing costs, including for housing (Shoup, 1999). For instance, Gössling *et al.* (2019) estimated that in the EU, car

¹ Climate change refers to the phenomenon of increasing global temperatures caused by the greenhouse gases (GHG) that trap heat in the Earth's atmosphere. The main GHG are: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and Fluorinated Gases (F-gases) (IPCC, 2018; US EPA, 2019).

usage represented an average cost for society of 0.11 € per km driven not covered by the driver, with the most important external cost factors being infrastructure construction (mainly roads and parking) and climate change. Conversely, the same report found that walking and cycling had, respectively, an external societal benefit of 0.37 € and 0.18 € per km (Gössling *et al.*, 2019).

However, breaking the car habit has proven to be a difficult challenge as modal choice is a complex decision influenced by individual (e.g., sociodemographic characteristics, attitudes), social (e.g., norms) as well as built (e.g., urban form, transport infrastructure) and natural (e.g., topography) environment factors (Javaid, Creutzig and Bamberg, 2020). As such, most policies and measures aimed at reducing car usage have so far revealed modest results (Ogilvie *et al.*, 2004; Graham-Rowe *et al.*, 2011). In that regard, Cox (2008) points that part of the challenge of reducing car usage relates to the fact that it is the default transport option for most citizens (and decisionmakers), suggesting that a possible way to challenge the car dominance is by introducing alternative modes of transport.

Troublingly, the current coronavirus pandemic has severely affected one of the major sustainable alternatives to the private car: Public Transport (PT), which could further exacerbate this overdependency on car usage. Infection fears and risks associated with having large numbers of passengers inside enclosed and often overcrowded vehicles have provoked historical ridership drops in PT systems across the world (Gkiotsalitis and Cats, 2020; MTA, 2021), which have yet to recover to pre-pandemic levels (APTA, 2022). As it is ever more likely that COVID-19 will continue to impact the world for years to come (Nature, 2022), there is a risk of a permanent PT ridership loss (Medlock, Temzelides and Hung, 2021). Even more worrisome, recent epidemiological research points that the intensity and frequency of new epidemics is increasing as a result of globalization, climate change, biodiversity loss and increased human-animal contact (Tollefson, 2020; Marani *et al.*, 2021; Haileamlak, 2022), putting additional constraints on transport systems. Thus, enhancing the resilience of transport systems, i.e., ensuring their ability to move people and goods during disruptions (Mattsson and Jenelius, 2015), while at same time improving their sustainability, has increased in importance in the political agenda.

As a response, cycling has started to gain attention as a possible solution, especially in urban areas (Pucher and Buehler, 2008; Buehler and Pucher, 2021). Not only is cycling a sustainable mode of transport, capable of considerable reductions in CO₂ emissions (Brand, Dons, *et al.*, 2021; Brand, Götschi, *et al.*, 2021; Wu Chen *et al.*, 2022), but the efficiency and versatility associated with the bicycle, capable of being accommodated in a small share of the existing road network, makes it an attractive transport option during disruptive events. For example, following high magnitude earthquakes in Japan and Mexico, which have severely damaged conventional transport networks like roads and rail tracks, bicycles were used by the affected populations as the fastest and safest transport option (Sonuparlak, 2011; Jong, 2017). Likewise, during Russia's war of aggression against Ukraine the bicycle has become one the main modes of transport in the most affected Ukrainian cities plagued by fuel shortages and destroyed PT systems (EC, 2022). Cycling became a particularly attractive alternative within the COVID-19 context (Buehler and Pucher, 2021) not only for its ability to social distancing, but also due to an increase in the importance of short trips at the local level (de Haas, Faber and Hamersma, 2020), as a result of geographical limitations on travelling, on which the bicycle is especially competitive (J. Dekoster, 1999; Ellison and Greaves, 2011).

One of the most popular policies promoting cycling is the implementation of bike sharing systems (BSS). These systems have witnessed a remarkable growth in the last decade with 2000 systems currently in operation in more than 1500 cities across the world, mainly in China, Europe and North America (Meddin Bike-sharing World Map Report, 2022). BSS consists on the short term renting of bicycles distributed across a network of stations (or predefined operational areas in the case of free-

floating or *dockless* systems), typically in an urban setting, enabling low cost point-to-point trips (Demaio, 2009; Shaheen, Guzman and Zhang, 2010; Fishman, 2016; Si *et al.*, 2019). The rise of BSS can be largely connected to the 3rd generation systems, with *Velo'v* (Lyon - 2005) and *Vélib'* (Paris - 2007) being among the first and most recognised examples (Demaio, 2009; Shaheen, Guzman and Zhang, 2010). These systems are characterised by incorporating ICT (information and communications technologies) that allow the operators to track in real-time the stations' capacity, with the more recent BSS also allowing to track the bike fleets' location through GPS (Demaio, 2009; Shaheen, Guzman and Zhang, 2010; Fishman, 2016; Si *et al.*, 2019). New generations of BSS have already emerged, namely the Chinese free-floating or *dockless* systems in 2016 (Si *et al.*, 2019) and, more recently, electric bike (e-bike) sharing systems (Munkácsy and Monzón, 2017). Figure 1 presents a brief history of the evolution of bike sharing, summarizing the main features characterizing the four main generations of BSS (Demaio, 2009; Shaheen, Guzman and Zhang, 2010; Munkácsy and Monzón, 2017; Si *et al.*, 2019).

1st Generation Amsterdam (1965): <i>Witte Fietsen</i>	• Conventional white painted bikes • Free of charge with unlocked bikes distributed across an area • System collapsed due to theft and vandalism
2nd Generation Copenhagen (1991): <i>ByCylken</i>	• Heavy duty bikes • Coin-operated locks • Vulnerable to theft due to anonymity of user
3rd Generation Lyon (2005): <i>Velo'v</i>	• IT-based systems • Electronically-locking docks • Ended users' anonymity reducing theft and vandalism
4th Generation China (2016): <i>Mobike, Ofo</i>	• Free-floating/dockless systems (without conventional stations) • Integration of mobile payment and GPS tracking with Big Data • Online <i>apps</i> with real time availability of bikes

Figure 1 – Main characteristics of the four generations of BSS (Demaio, 2009; Shaheen, Guzman and Zhang, 2010; Munkácsy and Monzón, 2017; Si *et al.*, 2019)

In that sense, bike sharing systems could offer a transport alternative to the car in urban areas, promoting a greater diversity of modal choice and, potentially, contributing to the transition from car travel to more sustainable modes of transport. Bike sharing could be especially useful during the current coronavirus pandemic (as well as similar disruptive events), providing an alternative to the battered PT systems and helping to prevent an increase on car use, while helping to ensure the mobility needs of citizens. As Cox (2008) puts it: “resilient and flexible transport systems for sustainable urban futures should exhibit diversity in their modes and potentials for mobility practices” (p. 145). Consequently, with more and more cities looking at bike sharing as a possible pathway to improve the sustainability and resilience of their transport systems, is it increasingly important to clarify the role that BSS can play in achieving this goal.

1.2. RESEARCH GOAL AND QUESTIONS

Following the previous line of thought, the main goal of this thesis is to assess the potential role of bike sharing towards increasing the sustainability, particularly by reducing car usage, and the resilience of urban transport systems during disruptive public health crises such as the current coronavirus pandemic. Based on this overarching goal, four research questions and one research sub-question were formulated (Figure 2).

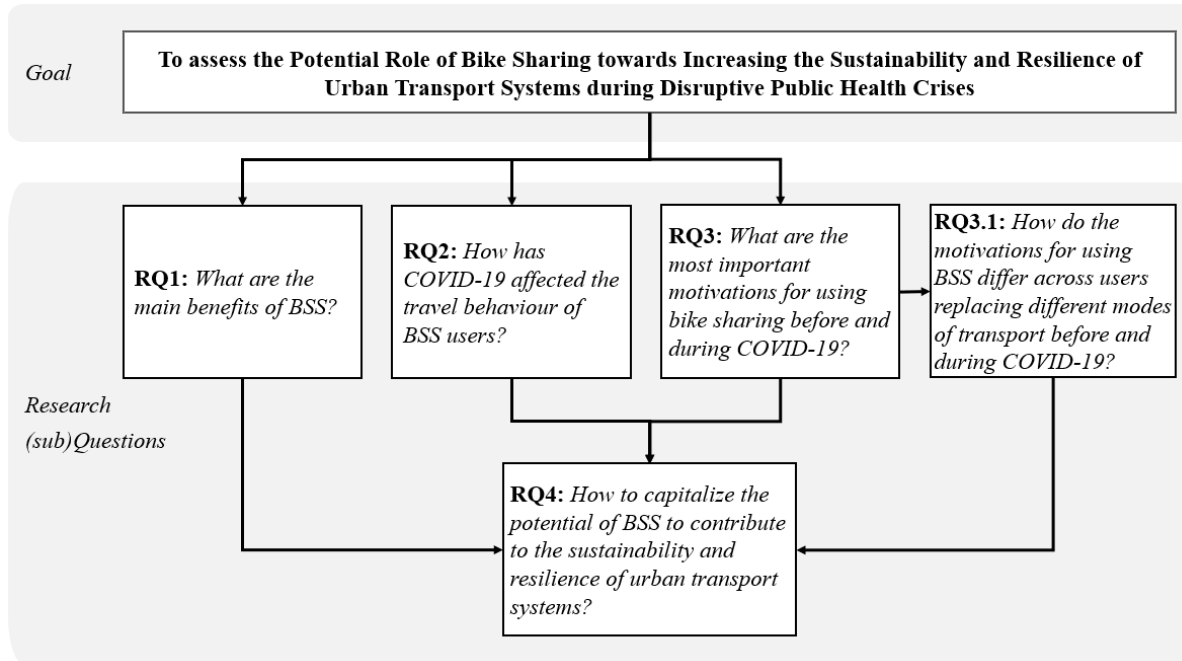


Figure 2 – Diagram of the goal and research (sub)questions of this thesis

RQ1	<i>What are the main benefits of BSS?</i>
------------	--

Even though hundreds of BSS have been implemented in the last two decades, their benefits continue to be the subject of contention (Médard de Chardon, 2019). For instance, one of the main reported reasons for implementing BSS is to reduce GHG emissions in the city, with municipalities and operators often stating that their systems are able to prevent the release of large amounts of GHG (Demaio, 2009; Médard de Chardon, 2016). Yet, most of these claims are not backed by actual data, instead relying on the assumption that all BSS trips are replacing car trips (Ricci, 2015; Médard de Chardon, 2016).

Therefore, this thesis starts by the premise of investigating the expected benefits from implementing a bike sharing system in a city, synthetizing the available evidence through a comprehensive literature review. Furthermore, the disruptive nature of the coronavirus pandemic and its impacts on transport systems, particularly PT, opens new opportunities to bike sharing, and, as such, the benefits of BSS during COVID-19 are also explored, including their potential contribution towards increasing the resilience of transport systems during these types of disruptive public health crisis.

RQ2***How has COVID-19 affected the travel behaviour of BSS users?***

The severity of the COVID-19 pandemic and its major impacts on mobility may result in long-lasting effects on travel behaviour. As such, in order to assess how the pandemic has influenced the potential of BSS to contribute to the sustainability and resilience of transport systems, it is first paramount to analyse the impacts of COVID-19 on the bike sharing systems themselves. Accordingly, this research question aims at evaluating how the coronavirus pandemic has affected the travel behaviour of BSS users, including their usage frequency and trip purposes, as well as the relationship of BSS with other modes (namely, multimodality and modal shift dynamics).

RQ3***What are the most important motivations for using bike sharing before and during COVID-19?***

The disruptive nature of the coronavirus pandemic and the subsequent policy responses to contain its spread has been particularly damaging for mobility, with physical interactions considered as an extremely high-risk behaviour due to potential COVID-19 infection. As a consequence, the coronavirus pandemic could have also changed the very motives for using bike sharing. For instance, faced with a perceived risk of infection for using public transport, users may now value much more using bike sharing as an alternative to PT. As such, a crucial research path is to investigate the motivations for using bike sharing during pandemics like COVID-19. Such insights could not only help to design BSS better prepared to these types of disruptive events, but also provide additional knowledge on the potential contribution of bike sharing towards increasing the sustainability and resilience of transport systems.

Consequently, **RQ3** builds upon the existent research on the motivators to BSS use by assessing motivations related to the impacts of COVID-19 and comparing their importance with the other known facilitators of BSS usage prior to the pandemic.

RQ3.1***How do the motivations for using BSS differ across users replacing different modes of transport before and during COVID-19?***

As the literature review will show, a substantial amount of BSS benefits is dependent on the systems' ability of shifting users from motorized modes of transport to BSS, especially car users. Understanding the reasons behind the decision of some car users to choose bike sharing could provide valuable information on how to enhance the competitiveness of BSS against the car, opening a possible path for increasing their ability of replacing car trips. The identification of the significant motivations associated with the different modes of transport being replaced could lead to a better understanding of the mode substitution capability of bike sharing, potentially providing key evidence on how to tailor and optimize BSS to induce further car use reductions. Furthermore, the scale of disruption provoked by the coronavirus pandemic could have led to changes on the attitudes and behaviour towards mobility, inducing new modal shift dynamics. Thus, this sub-research question explores possible differences on the main reasons for using bike sharing between users replacing car trips and users replacing other modes of transport both before and during COVID-19.

RQ4***How to capitalize the potential of BSS to contribute to the sustainability and resilience of urban transport systems?***

The literature review on the impacts of BSS suggests that their contribution towards sustainability (namely regarding reductions on CO₂ emissions) is deeply connected with the ability of these systems attracting users from motorized modes of transport, especially private car. At the same time, preliminary research points to bike sharing being more resilient to the coronavirus pandemic than PT, which has been severely affected by COVID-19.

Consequently, **RQ4** builds upon the previous research questions to assess how the potential contributions of BSS towards the sustainability and resilience of urban transport systems could be increased, namely by enhancing the BSS capability of acting as substitutes to private car and public transport. In here, users might be an important source of information for making decisions about improving bike sharing systems. Analysing the reasons for users to join BSS, examining their experiences on using the systems and listening to their concerns as well as their overall opinion towards bike sharing can deliver useful insights on how to improve the promotion of BSS, increasing their adoption, and ultimately providing a new sustainable and resilient transport option.

1.3. CASE-STUDY

1.3.1. THE MUNICIPALITY OF LISBON

This thesis has used the bike sharing system of Lisbon (named *GIRA*) as case-study. The main characteristics of Lisbon, Portugal's capital and most populous municipality, are shown in Table 1.

Table 1 – Lisbon main characteristics (population size, area, density) as well as the length of its road, metro and cycling network

Population characteristics	<i>City population</i>	504 964
	<i>City area (km²)</i>	100
	<i>Pop. density (inhab./km²)</i>	5 047.1
Transport infrastructure	<i>Cars per 1000 inhab. (country average)^a</i>	490.8
	<i>Road network extension (km)</i>	1 700
	<i>Km roads per 1000 inhab.</i>	3.4
	<i>Km metro lines</i>	44.5
	<i>Cycling network extension (km)</i>	125
	<i>Cycling network planned expansion (km)</i>	200 (+75)
	<i>Km cycling lanes (current) per 1000 inhab.</i>	0.21
	<i>Km cycling lanes (planned) per 1000 inhab.</i>	0.40

^a Car ownership in Portugal in 2017 (EEA, 2019)

According to the Portuguese National Institute of Statistics (INE, 2018), Lisbon has a population of 504 964 inhabitants with a population density of 5 047.1 inhab/km². The municipality of Lisbon is the core of Lisbon's Metropolitan Area, constituted by 18 municipalities totalizing an area of 3 015 km² and home of 2.8 million inhabitants (representing 27% of Portugal's population), concentrating most of its economic activity and employment (INE, 2018).

Furthermore, Lisbon (as well as the rest of its Metropolitan Area and indeed the country) has heavily invested in expanding its car infrastructure (including the construction of major highways and bridges

exclusively for cars). This has resulted in the municipality being predominantly car-oriented with almost half the trips made by car (45.1%), and a residual use of cycling as a mode of transport (0.6%) (Figure 3) (INE, 2018).

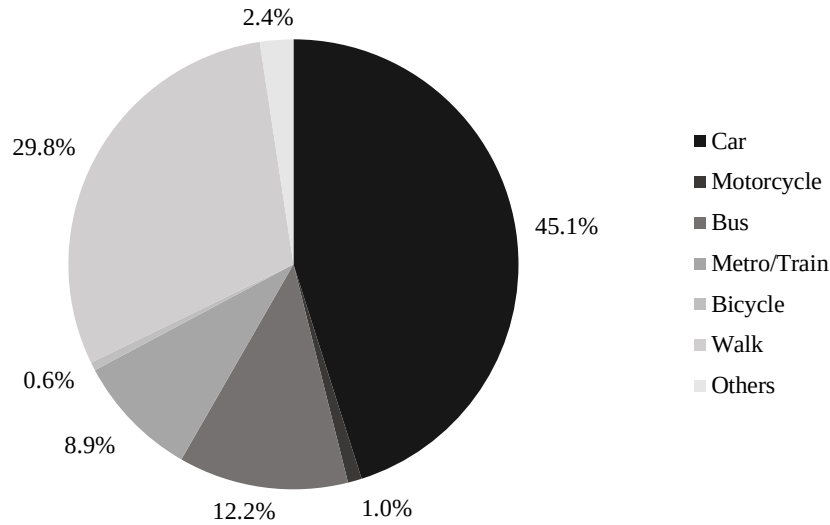


Figure 3 – Lisbon modal split in 2017 (INE, 2018)

Consequently, this heavy reliance on car use has led to substantial negative externalities to the municipality, namely its impact on CO₂ emissions and air quality. In fact, the transport sector is responsible for the biggest share of the municipality's CO₂ emissions, representing, in 2014, 40% of the total CO₂ emissions (Agência de Energia e Ambiente de Lisboa, 2014).

As such, Lisbon has started to promote cycling as a mode of transport with, arguably, the two most iconic measures of cycling promotion in the city being the construction of a dedicated cycling network, with a current length of 125 km and plans for expanding it to 200 km (Câmara Municipal de Lisboa, 2020a), and the implementation of a BSS entitled *GIRA*. Nevertheless, the city's transport infrastructure and public space continues to be dominated by the car as illustrated by Table 1, with the cycling network length (even when considering the expansion plan) being an order of magnitude lower than the road network length.

1.3.2. THE BIKE SHARING SYSTEM: *GIRA*

Implemented at the end of 2017, *GIRA* (Figure 4) is a docked system mostly comprised by electric bikes. Furthermore, *GIRA* is public owned by the Municipality and operated by EMEL, a municipality public company which is also responsible for the city's on-street parking management. The system began fully operating in September 2017 (after a pilot phase in June 2017), registering one million trips and 18 500 users subscribing annual passes after one year of operation (EMEL, 2018). Such metrics have led the city to consider *GIRA* a success and to conduct further expansions, with the aim of covering the whole city by 2030 (Câmara Municipal de Lisboa, 2020b).



Figure 4 – Example of a *GIRA* station in Lisbon

Figure 5 presents the distribution of *GIRA* stations across Lisbon in 2019 and in 2022, in which the system has considerably expanded from 74 stations (and 700 shared bikes) (EMEL, 2017, 2019a) to 138 stations (and 1600 shared bikes) (EMEL, 2022b). Even though the remarkable expansion on its size (doubling in both the number of stations and bicycles in 3 years), the system continues to be mostly concentrated in the city centre and in some parts of the riverside.

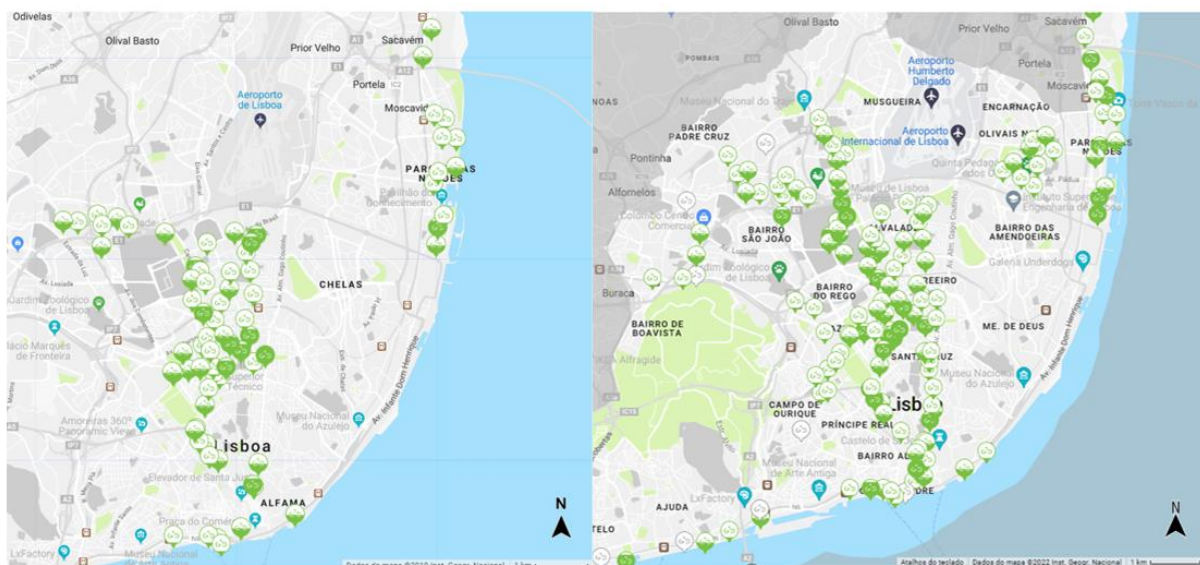


Figure 5 – *GIRA* stations across Lisbon in 2019 (left side) (EMEL, 2019a) and in 2022 (right side) (EMEL, 2022a)

Figure 6 presents the number of *GIRA* trips per month since it began operating (September 2017) until the end of 2020. By the end of 2022 *GIRA* had registered more than 6.5 million trips (EMEL, 2022b).

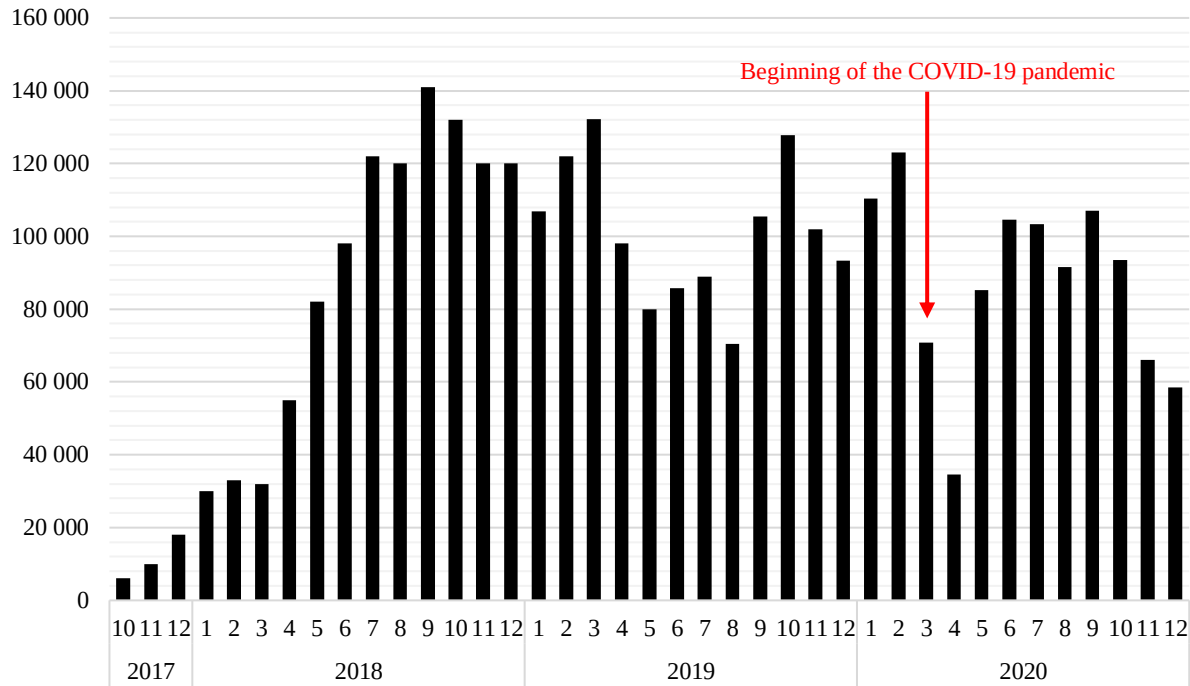


Figure 6 – Number of trips per month of *GIRA* since it became fully operational (end of 2017) until the end of 2020

As one of the main objectives of *GIRA* is to reduce car use in Lisbon, assessing in depth why some car users are being attracted to *GIRA* is of paramount importance. In addition, as the majority of *GIRA*'s bikes are electric, this case study presents an opportunity to further investigate the impact of e-bikes in modal shift dynamics, which are still largely not covered in the literature. Furthermore, Lisbon is a prime example of a starter cycling city, i.e., cities where cycling as a mode of transport is residual and that are still struggling to find the best approach to increase their cycling levels (BYPAD, 2008; Silva *et al.*, 2019). As such, evaluating how bike sharing could increase cycling use in Lisbon might provide additional insights on how to promote cycling in starter cities. Moreover, being the largest BSS in operation in Portugal, the assessment of *GIRA* and its success has the potential to serve as a benchmark for the deployment of future systems in the country. This is of special relevance as the new strategy of the Portuguese Government for promoting cycling directly cites the implementation of BSS as one of the measures to achieve its very ambitious strategy of increasing the country's cycling modal share, from the current 0.5% to 7.5% by 2030 (Presidência do Conselho de Ministros, 2019).

1.4. RESEARCH APPROACH AND METHODS

A mixed methods approach was chosen to accomplish the goal of this research. Mixed research methods have been gaining relevance in the last decades among researchers, including in transport studies (Clifton and Handy, 2003) and bike sharing (Fishman, 2014). Proponents of their use argue that the combination of both quantitative and qualitative approaches allows to achieve a more comprehensive understanding of the research problem than by employing either approach alone (Bryman, 2012a; Creswell, 2014b). Quantitative research allows the comparison and statistical aggregation of large numbers of subjects but is restricted to a limited number of questions typically pre-selected by the researcher (e.g., closed-ended survey questions), whereas qualitative approaches are able to provide

much more detailed data but are limited to a small number of subjects (Clifton and Handy, 2003; Beirão and Sarsfield Cabral, 2007). Thus, one of the major advantages of combining both research designs is the trade-off between the breadth provided by quantitative methods and the depth of qualitative approaches (Beirão and Sarsfield Cabral, 2007).

This research has followed an explanatory sequential mixed methods design (Creswell, 2014a), which consists in first conducting a quantitative analysis with the results obtained from this phase guiding the second qualitative phase (Figure 7) (Ivankova, Creswell and Stick, 2006; Creswell, 2014a). Thus, the aim is to utilize the qualitative data to explain in more detail the quantitative results (Creswell, 2014a). As Ivankova, Creswell and Stick (2006) explain: "... the qualitative data and their analysis refine and explain those statistical results [obtained from the quantitative phase] by exploring participants' views in more depth" (p. 5). In this research, a greater emphasis was given to the quantitative phase.

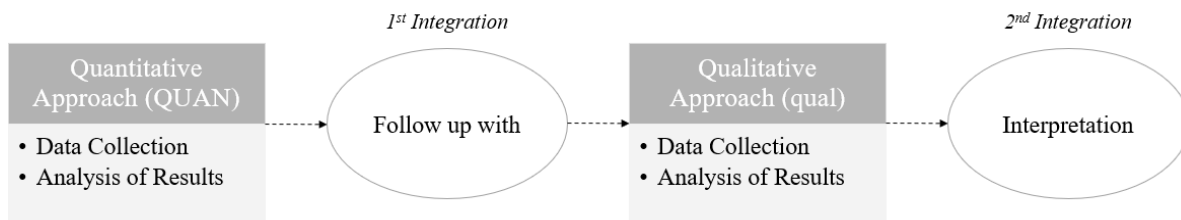


Figure 7 – Sequential explanatory design [adapted from (Creswell, 2014a)]. QUAN (uppercase) and qual (lowercase) indicate that the quantitative approach will be the primary method, with the qualitative approach complementing the first

The primary data collection instrument consisted of a cross-sectional travel survey, aimed at assessing the main impacts of COVID-19 in the travel behaviour (including modal shift dynamics, frequency and purpose for using bike sharing) and motivations of BSS users.

The qualitative phase purpose was to explore in more depth the COVID-19 impacts on the travel behaviour, preferences and motivations of BSS users as well as to gain additional and in-depth insights regarding the motivations identified in the travel survey as more significant to BSS usage. To that end, semi-structured interviews were employed as data collection instruments.

The quantitative and qualitative phases were connected at two stages of the research process (Figure 7). The first integration occurred at the intermediate stage, where the participants for the qualitative phase were selected from those who responded to the survey in the quantitative phase. Furthermore, the questions used in the semi-structured interviews were also based on the results of the quantitative analyses. The second integration occurred at the end of the research process, where the quantitative and qualitative results were discussed simultaneously to answer the research questions.

Thus, by combining the travel surveys' breadth with the depth of the semi-structured interviews, this thesis aimed at achieving a holistic understanding of the COVID-19 impacts on the travel behaviour and attitudes of BSS users. Figure 8 provides a detailed overview of the main phases, procedures and outputs obtained from the data collection instruments and methods employed in this thesis.

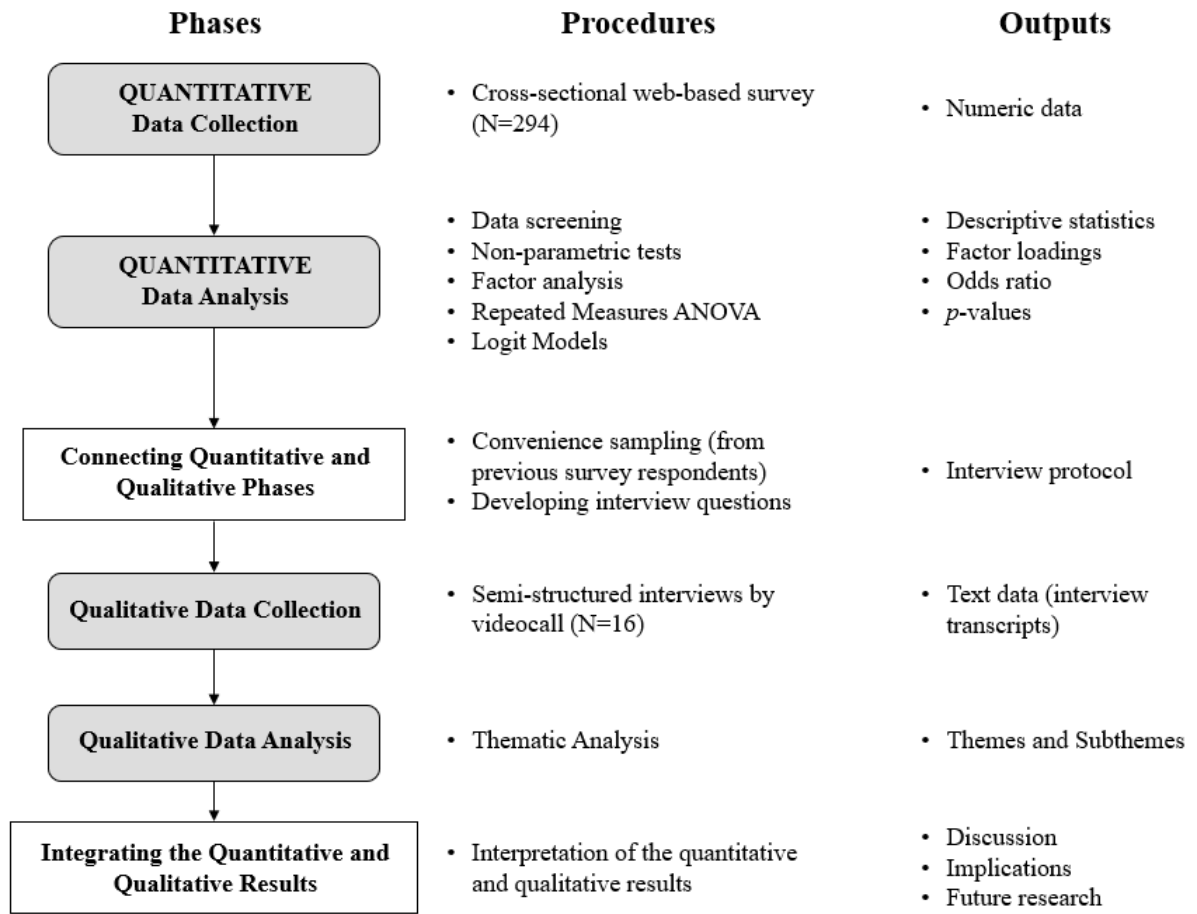


Figure 8 – Overview of the main methodological approaches employed in this thesis [adapted from (Ivankova, Creswell and Stick, 2006)]

1.4.1. DATA COLLECTION INSTRUMENTS

This thesis has employed a travel behaviour survey and semi-structured interviews as its main data collection methods, which are detailed next. The application of both instruments was reviewed and approved by the university's Data Protection Officer in compliance with the EU General Data Protection Regulation (GDPR).

1.4.1.1. TRAVEL SURVEY

A cross-sectional web-based survey was designed aimed at evaluating the travel behaviour, motivations and preferences of BSS users and how COVID-19 has affected them. In order to assess the coronavirus impact, the respondents were classified into four groups according with their relationship with *GIRA* (Lisbon's BSS and the case-study of this thesis) at the time of the survey:

- A.** *Being a GIRA user before and during the COVID-19 pandemic*
- B.** *Have joined GIRA during the COVID-19 pandemic*
- C.** *Being a GIRA user before the COVID-19 pandemic, but have stopped using the system as a result of the COVID-19 pandemic*
- D.** *Being a GIRA user before the COVID-19 pandemic, but have stopped using the system due to other reasons not related to COVID-19*

The answers of the respondents who have stopped using *GIRA* were considered to be related to the period before the pandemic, while the answers of the new users who have joined the system during COVID-19 to be related to the pandemic period. Furthermore, the respondents who were users before and during COVID-19 were asked to compare their behaviour before and during COVID-19. Consequently, with this categorization the answers from the respondents were categorized into two “distinct” periods of analysis:

- **Before COVID-19**, comprised by the combination of the retrospective questions asked to the respondents that continue to use the system (group **A**) and to the former users (groups **C** and **D**)
- **During COVID-19**, constituted by the combination of the answers from the new users (group **B**) and the answers of the respondents that continue to use the system in relation to the pandemic situation (group **A**)

Accordingly, Groups **A**, **B** and **C** allowed us to conduct direct analyses on the behavioural changes of *GIRA* users as a response to the pandemic (Chapter 4), while Group **D** was used in indirect analyses comparing the behaviour of *GIRA* users before and during COVID-19 (Chapter 5 and Chapter 6).

Three main groups of questions were considered, all of which with closed-ended responses. The first group aimed at assessing the travel behaviour of respondents, including their main mode of transport for commuting, frequency of BSS use, trip purpose, modal shift dynamics and the multimodal nature of BSS trips. The second group of questions focused on the motivations for BSS usage and the perceived safety of using different modes of transport in Lisbon before and during COVID-19. The last group of questions focused on the socioeconomic and demographic profile of the respondents. An overview of the survey structure is presented in Appendix A1, while the full questionnaire can be consulted in Appendix A2 (in Portuguese).

The survey was designed through the *limesurvey* platform, being available in an online-only format. The dissemination followed an opportunistic sample approach consisting of publicizing the survey in official pages of parish councils as well as pages and groups containing residents living or working in areas with BSS stations. Furthermore, the survey was widely publicized in cycling and bike sharing associations of Lisbon as well as in some faculties' mailing lists and in the local press. The survey was available between 22 of September and 27 of November, 2020. The time needed to complete the survey was between 10 min to 15 min. A total of 442 respondents opened the survey and indicated to use or have used *GIRA*, of which 294 completed the survey. Figure 9 presents the distribution of the completed questionnaires throughout the days².

² Initially the survey was scheduled to be only available until the end of October (with this sample being used in Chapter 4, published in a special issue on COVID-19 whose call closed at the beginning of December 2020). However, in late October one faculty accepted the previous request to disseminate the survey and, as the sample size was still modest by that time, it was decided to also include those answers in the subsequent studies (Chapters 5 and 6). Nevertheless, the completed questionnaires in November represent only 4.8% of the total sample (14 of the 294 answers).

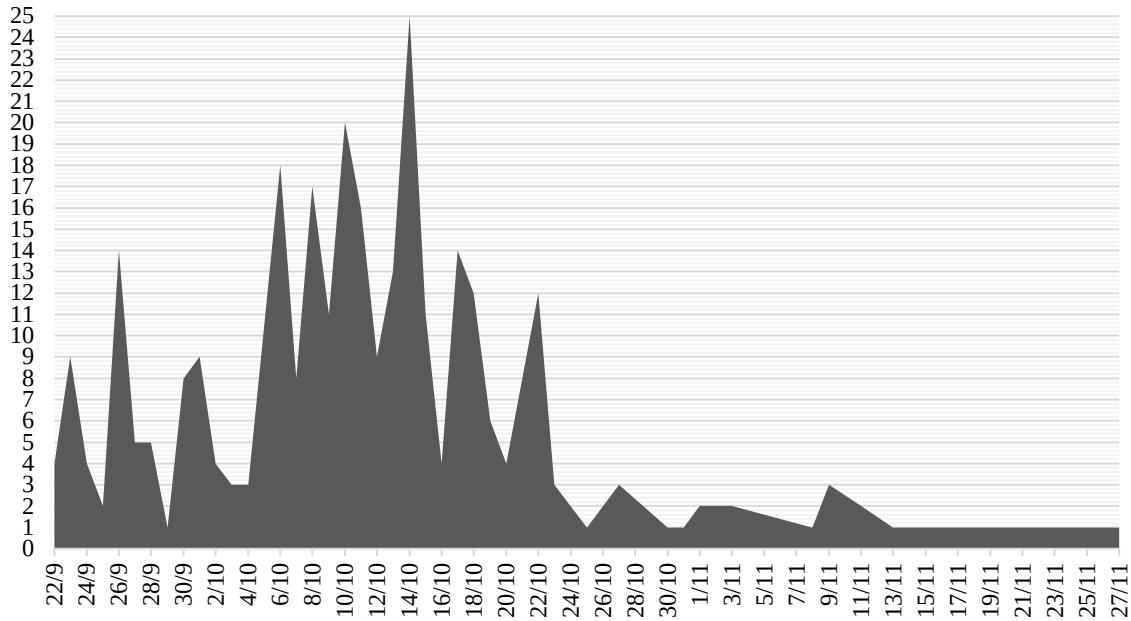


Figure 9 – Distribution of the valid answers to the 2020 survey (N=294)

Regarding the four groups of *GIRA*'s users, the respondents who were already *GIRA* users before COVID-19 and continued to use the system during the pandemic constitute the largest group (160 valid answers); followed by former *GIRA* users who no longer use the system due to other reasons not related to COVID-19 (69 valid answers); the new *GIRA* users who joined during the COVID-19 pandemic (35 valid answers); and, lastly, the former *GIRA* users who no longer use the system due to the COVID-19 pandemic (30 valid answers).

1.4.1.2. SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews were conducted following the implementation of the travel survey to the users of *GIRA* aimed at further investigating the COVID-19 impacts on their travel behaviour, preferences and motivations. As such, the interviewees were recruited through the previously mentioned survey, which had an option at the end for respondents interested in participating in a second research phase to leave their email. Invitations for study participation were sent to the respondents who provided valid emails (63 in total), with 16 individuals agreeing to be interviewed.

The interviews were conducted between 4 and 19 of November, 2021, through videocall, with an average duration of 15 min. A series of questions (mostly open-ended) were asked to the participants focused on the reasons for their decision to use *GIRA*, the impacts of COVID-19 on that usage as well as regarding *GIRA*'s relationship with other modes of transport. The list of the interview questions is provided in Appendix A5, while the full interview protocol can be found in Appendix A4 (in Portuguese).

1.4.2. MAIN DATA ANALYSIS METHODS

Both quantitative as well as qualitative methods were employed in this thesis. Statistical analyses were applied to the results of the travel survey. Descriptive statistics were used as a first assessment of the results, allowing the identification of possible relationships to be explored by more complex statistical methods. Specifically, descriptive methods were applied to analyse the impacts of COVID-19 in the

travel behaviour of the respondents (*GIRA* users), namely regarding their frequency and purpose of BSS usage, modal shift dynamics and multimodality. Likewise, descriptive statistics were also initially utilized to investigate the motivations for BSS usage, the reasons for quitting BSS and safety perceptions.

More complex statistical tests were then employed to further explore the results. Non-parametric Wilcoxon Signed Rank and Mann-Whitney U tests were applied, respectively, to assess changes on the importance of motivations for using BSS and on the safety perceptions of using different modes of transport due to the coronavirus pandemic. The motivations for using BSS before and during COVID-19 were further analysed through the use of exploratory factor analysis (EFA) and one-way repeated measures ANOVA, with the aim of ranking the most important motivations (summarized into a number of representative motivational factors) before and during COVID-19. Additionally, independent-samples *t*-tests were utilized to the motivational factors resulting from the EFA to investigate potential differences between the new and older users of BSS. As an additional validation of the results, the non-parametric equivalents of the one-way repeated measures ANOVA and the independent-samples *t*-tests were also conducted (respectively, Friedman test with pairwise Wilcoxon Signed Ranks post-hoc tests and the Mann-Whitney U test). Lastly, multinomial logit (MNL) models were also deployed aimed at investigating the relationship between modal shift from different modes of transport (specifically, private motor vehicles, PT and walking) and the motivations³ for using bike sharing both before and during the coronavirus pandemic.

Regarding qualitative methods, the data obtained from the semi-structured interviews was analysed through the use of Thematic Analysis, specifically the 6-step approach of Braun and Clarke (2006). The association between the employed quantitative and qualitative methods and each research question is provided in the next subsection (Table 3).

1.4.3. OVERVIEW AND ORGANIZATION OF THE PAPERS

A total of six papers were developed to answer the research questions, each one corresponding to a Chapter of the thesis (Table 2).

Table 2 – Published and submitted papers comprising this thesis-by-publication

Papers	Chapter
Teixeira, J. F., Silva, C. and Moura e Sá, F. (2021) 'Empirical evidence on the impacts of bikesharing: a literature review', <i>Transport Reviews</i> . Taylor & Francis. 41(3), pp. 329–351. doi: 10.1080/01441647.2020.1841328.	Chapter 2
Teixeira, J. F., Silva, C. and Moura e Sá, F. (2023) 'Potential of Bike Sharing During Disruptive Public Health Crises: A Review of COVID-19 Impacts', <i>Transportation Research Record</i> . SAGE, 0(0). doi: 10.1177/03611981231160537	Chapter 3

³ Initially, the motivational factors resulting from the EFA were used in the MNL. However, as no statistically significant differences were found when using the motivational factors, the individual motivations were used instead. Please consult Chapter 6 for more details.

Teixeira, J. F., Silva, C. and Moura e Sá, F. (2022) 'The role of bike sharing during the coronavirus pandemic: an analysis of the mobility patterns and perceptions of Lisbon's GIRA users', <i>Transportation Research Part A: Policy and Practice</i> . Elsevier. 159, pp. 17–34. doi: 10.1016/j.tra.2022.03.018.	Chapter 4
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Teixeira, J. F., Silva, C. and Moura e Sá, F. (2021) 'The motivations for using bike sharing during the COVID-19 pandemic: Insights from Lisbon', <i>Transportation Research Part F: Psychology and Behaviour</i> . Elsevier. 82, pp. 378–399. doi: 10.1016/j.trf.2021.09.016.	Chapter 5
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Teixeira, J. F., Silva, C. and Moura e Sá, F. (n.d.) 'Factors influencing modal shift to bike sharing: Evidence from a travel survey conducted during COVID-19', <i>Journal of Transport Geography</i> (Under Review).	Chapter 6
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Teixeira, J. F., Silva, C. and Moura e Sá, F. (2022) 'The strengths and weaknesses of bike sharing as an alternative mode during disruptive public health crisis: A qualitative analysis on the users' motivations during COVID-19', <i>Transport Policy</i> . Elsevier. 129, pp. 24–37. doi: 10.1016/j.tranpol.2022.09.026.	Chapter 7
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1.4.3.1. CHAPTER 2 – EMPIRICAL EVIDENCE ON THE IMPACTS OF BIKESHARING: A LITERATURE REVIEW

Chapter 2 was the first study developed in this thesis and consists of a literature review synthesising the available evidence on the contribution of bike sharing towards sustainability (environment, health, social and economic benefits) and its relationship with other modes of transport (with a special focus on car use). A total of 77 studies from across the world were included in this review, with 69 being peer-reviewed articles. In addition to directly contributing to answering **RQ1** and **RQ4**, the findings from this review, namely the fact that most major benefits of bike sharing are dependent on its ability to reduce car usage, present one of the main foundations for the subsequent studies.

1.4.3.2. CHAPTER 3 – THE POTENTIAL OF BIKE SHARING DURING DISRUPTIVE PUBLIC HEALTH CRISES: A REVIEW OF COVID-19 IMPACTS AND POLICY RESPONSES

Chapter 3 consists of a literature review synthesizing the available research published during the first two years of the pandemic regarding the impacts of COVID-19 (**RQ2**) on bike sharing as well as the subsequent policy responses that affected the operation of BSS. A total of 58 studies were included in this review, of which 39 are peer-reviewed papers. In addition to supporting **RQ2**, this study also further develops the potential contributions of bike sharing during disruptive public health events like COVID-19 (**RQ1** and **RQ4**). Due to the novelty of COVID-19, which meant that a review article could only be conducted when there was already some published literature, this was the last study developed within the scope of this PhD thesis. Furthermore, considering that the studies conducted during this thesis are an important part of such literature, the papers that were already published at the time of the literature review (specifically, the papers of Chapter 4 and Chapter 5) were also included.

1.4.3.3. CHAPTER 4 – THE ROLE OF BIKE SHARING DURING THE CORONAVIRUS PANDEMIC: AN ANALYSIS OF THE MOBILITY PATTERNS AND PERCEPTIONS OF LISBON'S *GIRA* USERS

Chapter 4 is the first empirical study deriving from the survey to the BSS users of Lisbon (*GIRA* system). Through using descriptive statistics and non-parametric tests (specifically, Wilcoxon Signed Rank and Mann-Whitney U tests), this study provides evidence of the main pandemic impacts by comparing the travel behaviour of *GIRA* users (**RQ2**) and their motivations for using bike sharing (**RQ3**) before and during COVID-19. Furthermore, it is the first study exploring the potential role of bike sharing in increasing the resilience of transport systems to disruptive public health crises (**RQ4**), a new potential benefit of BSS (**RQ1**). The findings from this paper provide a basis for the development of the subsequent three papers.

1.4.3.4. CHAPTER 5 – THE MOTIVATIONS FOR USING BIKE SHARING DURING THE COVID-19 PANDEMIC: INSIGHTS FROM LISBON

Chapter 5 delves on the main reasons for using bike sharing and further explores the impacts of COVID-19 on those motivations. Through employing EFAs and one-way repeated measures ANOVAs, five major motivational factors are identified and ranked according to their importance regarding the usage of BSS before and during COVID-19 (**RQ3**). Moreover, independent-samples *t*-tests were employed to investigate differences on the motivational factors between the respondents who had joined *GIRA* during the pandemic and those who were already users before COVID-19 and continued to use *GIRA* during the pandemic. The major finding that the *Social Discomfort* factor (constituted by using *GIRA* to avoid PT and to maintain a social distance) is now amongst the most important motivators for BSS usage further reinforces the potential contribution of bike sharing towards the resilience of transport systems (**RQ1** and **RQ4**).

1.4.3.5. CHAPTER 6 – FACTORS INFLUENCING MODAL SHIFT TO BIKE SHARING: EVIDENCE FROM A TRAVEL SURVEY CONDUCTED DURING COVID-19

Based on the literature review findings (Chapter 2), which exposes that a substantial amount of BSS benefits is dependent on the systems' ability of attracting car drivers, Chapter 6 investigates possible differences on the main reasons for using bike sharing between users replacing car trips and users replacing other modes of transport (**RQ3.1**). Through using MNL models, this paper identifies key features that are currently influencing car users to shift to BSS, and which could help to increase the capability of bike sharing to reduce car usage (**RQ4**).

1.4.3.6. CHAPTER 7 – THE STRENGTHS AND WEAKNESSES OF BIKE SHARING AS AN ALTERNATIVE MODE DURING DISRUPTIVE PUBLIC HEALTH CRISIS: A QUALITATIVE ANALYSIS ON THE USERS' MOTIVATIONS DURING COVID-19

Building on the results from the previous papers, Chapter 7 explores in more depth the individual behavioural changes provoked by coronavirus, particularly regarding their motivations and safety perceptions, on BSS users (**RQ2** and **RQ3**), better understanding why they have chosen to use bike sharing during the pandemic instead of other available modes of transport (**RQ3.1**). By using semi-structured interviews and through employing Thematic Analysis, this study also identifies the major factors that influence the competitiveness of these systems (**RQ1** and **RQ4**), including against the car.

As a summary, Table 3 presents the connection between each research (sub)question and each chapter as well as the associated main methods for data collection and analysis.

Table 3 – Research questions as well as the associated data collection instruments, main methods and chapters

Research Question	Data Collection	Main Methods	Chapter
RQ1: What are the main benefits of BSS?	Secondary data	Literature Review	Chapter 2 Chapter 3
	Travel Survey	Descriptive statistics Non-parametric tests Exploratory Factor Analysis (EFA) One-way repeated measures ANOVA	Chapter 4 Chapter 5
	Semi-structured Interviews	Thematic Analysis	Chapter 7
RQ2: How has COVID-19 affected the travel behaviour of BSS users?	Secondary data	Literature Review	Chapter 3
	Travel Survey	Descriptive statistics Non-parametric tests	Chapter 4
	Semi-structured Interviews	Thematic Analysis	Chapter 7
RQ3: What are the most important motivations for using bike sharing before and during COVID-19?	Travel Survey	Descriptive statistics Non-parametric tests Exploratory Factor Analysis (EFA) One-way repeated measures ANOVA	Chapter 4 Chapter 5
	Semi-structured Interviews	Thematic Analysis	Chapter 7
RQ3.1: How do the motivations for using BSS differ across users replacing different modes of transport before and during COVID-19?	Travel Survey	Descriptive statistics Multinomial logit (MNL)	Chapter 6
	Semi-structured Interviews	Thematic Analysis	Chapter 7
RQ4: How to capitalize the potential of BSS to contribute to the sustainability and resilience of urban transport systems?	Secondary data	Literature Review	Chapter 2 Chapter 3
	Travel Survey	Descriptive statistics Non-parametric tests Exploratory Factor Analysis (EFA) One-way repeated measures ANOVA Multinomial logit (MNL)	Chapter 4 Chapter 5 Chapter 6
	Semi-structured Interviews	Thematic Analysis	Chapter 7

1.5. THESIS STRUCTURE

Chapter 1 provided an overview of this thesis-by-publication, including the contextualization and importance of the research topic (subsection 1.1.), the main research questions (subsection 1.2.), the case-study (subsection 1.3.) and the research approaches employed (subsection 1.4).

After this introductory Chapter where the research rationale was exposed, the studies that constitute this thesis-by-publication are introduced. The first two Chapters (Chapter 2 and Chapter 3) consist of literature reviews, while Chapter 4 to Chapter 7 are empirical studies.

The thesis ends with Chapter 8, which provides a summary of the main contributions structured around answering the initial research questions (subsection 8.1.) and goal (subsection 8.2.) as well as policy insights both to decisionmakers and BSS operators (subsection 8.3.). The chapter ends by presenting the main limitations of this thesis and future research needs in the field of bike sharing (subsection 8.4.). It is then followed by the list of references and the appendices.

Table 4 – Organization of the remaining Chapters of this thesis and its connection to the research questions (RQ)

	RQ1	RQ2	RQ3	RQ3.1	RQ4
<i>Chapter 2</i>					
<i>Chapter 3</i>					
<i>Chapter 4</i>					
<i>Chapter 5</i>					
<i>Chapter 6</i>					
<i>Chapter 7</i>					
<i>Chapter 8</i>					

2.

EMPIRICAL EVIDENCE ON THE IMPACTS OF BIKESHARING: A LITERATURE REVIEW

This chapter presents an integral reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (2021) ‘Empirical evidence on the impacts of bikesharing: a literature review’, Transport Reviews. Taylor & Francis. 41(3), pp. 329–351. doi: 10.1080/01441647.2020.1841328.”

ABSTRACT

In recent years, bikesharing has become one of the most popular policies promoting cycling across the world. As the number of bikesharing systems (BSS) continues to rise, it is increasingly important to quantify their expected benefits. This paper synthesises the available evidence on the current impacts of implementing a BSS, with a special focus on the induced modal shift dynamics and impacts in car reduction, indicating how increasing the attractiveness of BSS to car users could improve its benefits. Several benefits have been associated to bikesharing, but they are not equally distributed and are dependent on several nuances, particularly on modal shifts. Among the biggest contributions are the increases in physical activity (PA) levels (triggering health gains) as well as travel time savings to the BSS users. Bikesharing is mostly replacing sustainable modes of transport, with modest car replacing rates. However, bikesharing can also indirectly decrease car travel by fostering synergies with Public Transport (by expanding catchment areas, reducing overcrowding and overall travel times) and by promoting cycling use through increasing the number and diversity of cyclists. Furthermore, different types of modal shift lead to different benefits. Reductions in car travel induce decreases in greenhouse gases (GHG) and other air pollutants, increases in PA, time savings as well as congestion reductions. Conversely, new trips generated by BSS also lead to increases in PA, while modal shift from walking to BSS has been associated with travel time savings. Shifting PT users to BSS can also reduce overcrowding in saturated PT networks. The most social disadvantaged groups were found to be systematically under-represented among BSS users, yet equity measures combined with awareness-raising campaigns could increase usage rates. Exploring potential advantages of BSS against car use and increasing its car replacing rates, coupled with better impact assessments, should constitute research priorities.

KEYWORDS: Bikesharing; Impacts; Sustainable transport; Modal shift dynamics; Reductions in car use

2.1. INTRODUCTION

Taking advantage of new technological advances and the promotion of cycling as an alternative to cars in urban areas, bikesharing systems (BSS) have seen an incredible growth with more than 2000 systems currently in operation mainly in China, Europe and North America (DeMaio and Meddin, 2020).

BSS consists of the short-term renting of bicycles distributed across a network of stations (docked systems) or predefined operational areas (*dockless* systems), typically in an urban setting, enabling low-cost point-to-point trips (Demaio, 2009; Fishman, 2016). The rise of BSS can be largely connected to the 3rd generation systems, with *Velo'v* (Lyon - 2005) and *Vélib'* (Paris - 2007) being among the first and most recognised examples (Shaheen, Guzman and Zhang, 2010). These systems are characterised by incorporating ICT that allow operators to track in real-time the stations' capacity, with the more recent BSS also capable to track the bike fleets' location through GPS (Shaheen, Guzman and Zhang, 2010; Fishman, 2016). Since the popularity of the 3rd generation systems, bikesharing has continued to rapidly evolve, first with the emergence of the Chinese *dockless* systems and now with the incorporation of electric assisted bikes (e-bikesharing).

Thus, it is increasingly important to clarify what is the role of bikesharing, especially concerning its possible contribution in tackling the present overreliance on car use and, consequently, increasing the sustainability of our transport system. As such, the primary aim of this study is to provide evidence on both the existing benefits of implementing a BSS, with a special focus on reducing car use, and how much of those benefits could be increased by improving the effectiveness of BSS against car travel. The rest of the paper is structured as follows. Next, the main procedures employed in the data collection and analysis are detailed. Then, the available evidence of the BSS impacts on sustainability is reported, being divided into four main themes: environment, health, equity, and economy. This is followed by the evaluation of the current BSS impact on car use and of possible synergistic relations with other modes (specifically public transport and cycling in general). We then highlight the main research outcomes and shortfalls, exploring possible paths to increase the confidence levels of the quantified benefits as well as the role that bikesharing can have in reducing car use.

By building on the existent literature, including the previous three literature reviews on bikesharing (Fishman, Washington and Haworth, 2013; Ricci, 2015; Fishman, 2016), this paper ultimately aims at presenting a complete analysis on the expected impacts of bikesharing and on how to improve its contribution towards a more sustainable mobility.

2.2. METHODOLOGY

The literature reviewed in this study was collected through three phases (Figure 10). First, peer-reviewed papers were retrieved from the scientific databases of *Scopus* and *Web of Science*, using search word combinations of "bikesharing", "bike sharing", "bikeshare", "bicycle sharing" and "impact*", "benefit*". Backward snowballing was then employed to the selected papers to examine the cited references on impacts. Finally, the peer-reviewed literature findings were complemented with analyses of grey literature namely reports from public agencies. Only documents written in English were considered. As inclusion criteria the identified studies had to deliver some sort of impact assessment of BSS in operation. A total of 77 studies were included in this analysis, of which 68 are peer-reviewed articles. The review encompasses studies published between 2009 and 2019 from Asia, Europe, North America, and Australia. Most of the research found pertains to conventional docked BSS, with only two studies referring to e-bikesharing (Campbell *et al.*, 2016; Otero, Nieuwenhuijsen and Rojas-Rueda, 2018) and another two related to *dockless* systems (Qiu and He, 2018; Zhang and Mi, 2018).

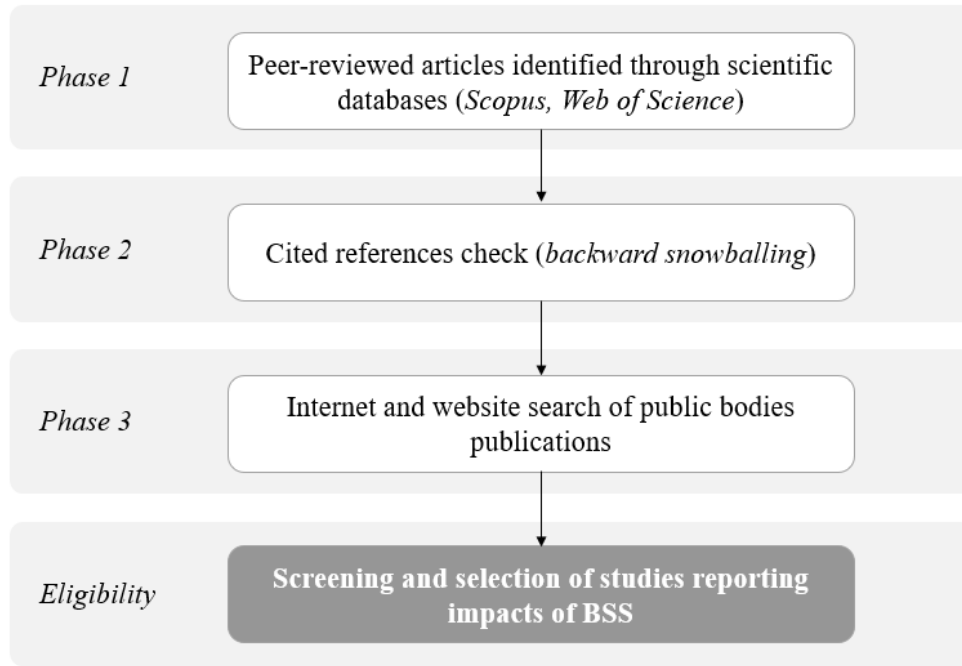


Figure 10 – Flowchart of data selection

As the next sections will show, a diversity of fields, including travel behaviour, transport planning and public health, have looked into the impacts of bikesharing, encompassing a wide range of impacts, from major environmental assessments to the effects on the real-estate market.

2.3. BSS AND SUSTAINABILITY

We first start by reviewing the available evidence on the potential contribution of bikesharing towards sustainability, with a special emphasis on assessing the benefits of shifting car users to BSS. Four main dimensions were explored:

- The potential environmental benefits (2.3.1.) by reducing emissions of GHG and other air pollutants
- The ability to induce public health gains (2.3.2.) by increasing PA levels
- The contribution to social equity (2.3.3.), focusing on the equity of access to BSS
- The expected economic gains (2.3.4.), through time savings and reduced congestion, local economies enhancements and other wider economic benefits

2.3.1. ENVIRONMENT

Environmental gains are amongst the most publicized benefits of bikesharing, especially the reductions in GHG. Municipalities and operators often state that their systems are able to prevent the release of large amounts of GHG (Demaio, 2009; Médard de Chardon, 2016). However, those environmental benefits are heavily dependent on the contingency of BSS replacing car trips. Consequently, we often find studies overstating environmental gains of BSS by relying on the assumption that all or most BSS trips are replacing car trips (Ricci, 2015; Médard de Chardon, 2016). For instance, recent assessments of Chinese *dockless* BSS quantified remarkable environmental gains. Yongping Zhang and Mi (2018), by using data from *Mobike* of Shanghai, estimated annual savings of 25,240 tonnes in CO₂ and 64 tonnes in NO_x emissions. Even more impressive, the assessment of Beijing's BSS estimated, for 2015, reductions of 616,040 tonnes in CO₂ emissions (Qiu and He, 2018). However, these estimations were

based on extremely high car replacing rates with, for example, Qiu & He (2018) assuming that 75% of all BSS trips were replacing car trips.

Fishman, Washington, & Haworth (2014) provide a more realist impact of BSS on car use, and subsequently on potential environmental gains. They assessed five BSS in operation (London, Brisbane, Melbourne, Minnesota, and Washington D.C.) by combining BSS trip logs with travel behaviour surveys and data from vehicles used in rebalance and maintenance operations. The surveys revealed most BSS trips to be substituting PT and walking trips, whereas the vehicles used by the BSS operators revealed heavy fuel consumption. Comparing the avoided distances travelled by car with the distances travelled by the rebalancing and maintenance vehicles, the study revealed an actual increase in the annual distances travelled. However, this increase results from London's BSS (by far the largest system) due to its residual modal shift from car, combined with the heavy reliance on trucks for rebalancing operations. The remaining cities all had a reduction on annual distances travelled by car (Fishman, Washington and Haworth, 2014).

A broader perspective is provided by Zheng et al. (2019) through the first known life-cycle analysis (LCA) of bikesharing, balancing the environmental gains from modal shifts to BSS with its life-cycle environmental impacts. Combining the travel behaviour surveys data of Chinese BSS users with LCA, they assessed eleven environmental categories (global warming, fossil depletion, freshwater ecotoxicity and eutrophication, human toxicity, ionizing radiation, marine ecotoxicity and eutrophication, metal depletion, PM formation, and photochemical oxidant formation). Bikesharing presented environmental gains in ten of the eleven categories evaluated, with only a negative impact on metal depletion. Among the results, Zheng et al. (2019) estimated an equivalent of 52.08 kg of CO₂ savings per BSS user per year, with 80% of the environmental gains resulting from reductions in motorized travel.

These studies illustrate the potential environmental gains of shifting car users to BSS, but they also highlight the need of reliable data on modal shift tendencies among BSS users to produce realistic environmental assessments. Likewise, they demonstrate that such environmental balances are far from straightforward as factors like the type of rebalancing vehicles employed or the lifetime of the shared bikes can also significantly impact the BSS environmental sustainability.

2.3.2. HEALTH

Bikesharing has the potential to induce substantial health benefits by promoting active travel, which has been established as inducing health gains particularly when comparing with car use (Rabl and de Nazelle, 2012; Mueller *et al.*, 2015). Three comparative risk assessment studies have been conducted to evaluate the health impacts of BSS. While considering different methodologies, they centred on the same three categories: changes in physical activity (PA) rates, exposure to air pollution (PM_{2.5}) and to road traffic crashes, focussing on the modal shift dynamics of BSS users (Rojas-Rueda *et al.*, 2011; Woodcock *et al.*, 2014; Otero, Nieuwenhuijsen and Rojas-Rueda, 2018). Rojas-Rueda *et al.* (2011) conducted the first known peer-reviewed health impact study of BSS, estimating a net benefit of 12.28 avoided deaths per year among Barcelona's BSS (*Bicing*) users comparatively to car drivers. However, as the authors lacked data regarding modal shifts, they assumed that 90% of *Bicing*'s users were shifting from car. Woodcock *et al.* (2014) had access to more reliable modal shift data and modelled the health impacts of the London's BSS by comparing those impacts with a scenario where the system did not exist. Although Woodcock *et al.* (2014) quantified health benefits, those were higher for men than for women because of higher traffic related injuries among women in London, and for older than for younger users due to the higher baseline mortality risk of the older population. The recent broad review of twelve large-scale European BSS conducted by Otero *et al.* (2018), estimated a total of 5.17 deaths

avoided per year due to car trips replaced by bikesharing, with benefits (from PA increases) outweighing the risks in all cities. Furthermore, Otero et al. (2018) demonstrated that the gains could be substantially increased if the BSS had higher car replacing rates.

Those increases in PA could induce obesity reductions, as evidenced by Xu (2019). By merging BSS data with CDC obesity prevalence statistics at the county-level in the USA, Xu (2019) found an average 1% decrease in obesity rates after the BSS implementation, although the use of county-level data may have led to an overestimation of the effects (Hosford, Winters and Fuller, 2019). Molina-García *et al.* (2015), through an 8-month follow-up cross-section study surveying university students in Valencia (Spain), estimated that BSS provided half of the recommended weekly PA level, leading to reductions in body-mass indexes and weight.

Regardless of the different approaches and considerations, it emerged as essential to have reliable data on the modal shifts due to bikesharing to produce realistic health impact assessments of BSS. Moreover, the PA gains rely on the BSS' ability in inducing modal shifts from motorized modes of transport (especially car) or in generating new trips. If most of the modal shift is from active modes, the gains will be minimal or even negative (Fishman, Washington and Haworth, 2015). Also, if most BSS users were already meeting the recommend PA levels and simply switched their previous exercise routines for bikesharing, the gains will be hindered (Bauman *et al.*, 2017).

Conversely, the exposure of BSS users to traffic crashes and air pollution could negatively offset health gains. Nevertheless, the current evidence reveals these risks to be on the scale of cycling in general (Fuller, Gauvin, Morency, Kestens, *et al.*, 2013; Woodcock *et al.*, 2014; Fishman and Schepers, 2016). For instance, Fuller, Gauvin, Morency, *et al.* (2013) investigated the traffic risks of *BIXI* users (Montreal's BSS) through three cross-sectional surveys (at launch and at the end of the first and second seasons of *BIXI*). The study indicated that there was no change in the likelihood of reported collisions or near misses, even though the city's cycling levels had increased (Fuller, Gauvin, Morency, Kestens, *et al.*, 2013). These results seem to be in line with the safety in numbers hypothesis, where an increase in the number of cyclists does not lead to a proportional increase in the number of injuries (Jacobsen, 2003; Fuller, Gauvin, Morency, Kestens, *et al.*, 2013). Some data seems to point that the injury risk may be even lower for BSS users (Woodcock *et al.*, 2014; Fishman and Schepers, 2016). Fishman and Schepers (2016), comparing hospital injury data of ten North American cities (five with BSS and five as control), revealed a decrease on cyclists' injury risk after the BSS implementation, with the risk decrease large enough to outbalance the increase on cycling use. Possible explanations include lower speeds or more awareness among car drivers (Fishman and Schepers, 2016), but this trend requires further research.

Hence, current evidence points that in most contexts the health benefits provided by increasing PA levels outweigh the harms from exposure to traffic crashes and air pollution. Indeed, a recent analysis of New York City's BSS revealed the system to be on par with the most cost-effective preventive public health interventions (Yu *et al.*, 2018). Still, it should be noted that the available literature assessing the health impacts of BSS is largely limited to high-income countries which tend to have higher traffic safety standards (WHO, 2018) and lower air pollution concentrations (Tainio *et al.*, 2016). Thus, in countries with more adverse conditions such findings may not hold as already observed in broad health assessments of active travel within cities with extreme pollution levels (Tainio *et al.*, 2016). Conversely, BSS could also decrease both pollution levels and traffic injury risks (by reducing car use), which would further lessen possible negative health impacts, but such analyses have not been conducted so far.

2.3.3. SOCIAL EQUITY

Virtually in any country, the most social disadvantaged groups tend to suffer from transport poverty, having lower car ownership rates and being served (or not served at all) by inefficient PT systems, which hinders their ability to access job opportunities, education and healthcare (Lucas *et al.*, 2016). Bikesharing can ameliorate these problems by providing an affordable and flexible transport alternative (Shaheen, Guzman and Zhang, 2010). Furthermore, by incentivizing physical activity, BSS can deliver additional gains for the most social disadvantaged, as these groups tend to have higher obesity rates (Kretman Stewart, Johnson and Smith, 2013; Xu, 2019).

However, equity assessments from the UK and North America revealed that, in addition to gender unbalances (men are much more likely to use BSS than women in those countries), the most disadvantaged groups (including low-income, less educated and ethnic minorities) are systematically under-represented among BSS users. In London, both F. Ogilvie & Goodman (2012) as well as Goodman and Cheshire (2014) found females and residents in deprived areas to be severely underrepresented among users of London's BSS. The system's expansion to more deprived areas and the introduction of casual trips have ameliorated some of these inequalities, but the doubling of prices that occurred after the expansion may have disproportionately impacted casual trips among poorer residents (Goodman and Cheshire, 2014). In North America, Ursaki and Aultman-Hall (2016) found statistically significant differences in race, education level and income in Chicago, Denver, Seattle and New York City; race and income in Boston; and income in Washington D.C. (which was the most equitable). McNeil, Broach, & Dill (2018) observed BSS usage rates among lower-income and minorities to be lower than those of higher-income white residents in Brooklyn, Chicago, and Philadelphia.

The main reasons for these inequalities are the location of BSS, which tend to be concentrated near city centres to take advantage of densification (both in population and activities) and many of these systems requiring the use of credit/debit cards (Ogilvie and Goodman, 2012; Goodman and Cheshire, 2014; Ursaki and Aultman-Hall, 2016; McNeil, Broach and Dill, 2018). Even when equity policies are implemented, the disadvantaged groups tend to be unaware of their existence (hindering their effectiveness), due to being much less likely to have friends or family using the systems and having less access to the Internet or smartphones (McNeil, Broach and Dill, 2018). These findings are further validated by Bernatchez, Gauvin, Fuller, Dubé, & Drouin (2015), which through a two-years study, correlated changes in awareness levels with the proximity to *BIXI* stations and levels of education among the population. Bernatchez et al. (2015) found that, although awareness levels were increasing over time, lower education was associated with lower awareness levels.

Nevertheless, these groups have as much interest as their counterparts in using bikesharing (McNeil, Broach and Dill, 2018), even showing higher usage rates per capita than the general population (Ogilvie and Goodman, 2012). Therefore, the more disadvantaged groups could potentially increase their BSS usage rates with proper policy support, namely by expanding the systems to deprived areas while maintaining them affordable and complementing it with target marketing campaigns (Ogilvie and Goodman, 2012; Goodman and Cheshire, 2014; Ursaki and Aultman-Hall, 2016; McNeil, Broach and Dill, 2018). This, in turn, would improve the contribution of bikesharing in decreasing the current accessibility gap found between car-owning and car-less groups (Martens, Golub and Robinson, 2012).

2.3.4. ECONOMY

Modal shifts to BSS could enable significant economic gains through reducing travel times. Jensen, Rouquier, Ovtracht, & Robardet (2010), analysing data from *Velo 'v* (Lyon's BSS), found 68.2% of the system's trips to be shorter than car trips leading to an average distance reduction of 13%. Furthermore, users of *Velo 'v* were reaching average speeds of 14.5 km/h in morning rush, close to the average car speeds in European urban cores (Jensen *et al.*, 2010). Similarly, Woodcock *et al.* (2014) estimated an average 20% reduction in travel times as a result of shifting to the London's BSS. Likewise, Faghih-Imani, Anowar, Miller, & Eluru (2017), comparing O/D pairs and travel times between BSS and taxis in New York City, discovered BSS to be either faster or competitive with taxi for more than half of the O/D pairs within distances less than 3 km.

One of the most comprehensive economic appraisals of bikesharing was conducted by Bullock, Brereton, & Bailey (2017). Using survey data from Dublin's BSS (*Dublinbikes*), they estimated the economic impacts from modal shift translated into environmental and health gains, time savings as well as other wider economic benefits (WEBs) such as agglomeration gains. Even though the environmental and health gains were low due to most of *Dublinbikes*' modal shift arising from walking (88.5% in this study), considerable economic gains deriving from time savings and WEBs were quantified. In fact, shifting from walking to BSS provided significant trip time savings leading to connectivity and accessibility improvements between home/PT stations and workplaces, which in turn provided substantial agglomeration benefits. Bullock *et al.* (2017) then conducted a cost-benefit analysis of *Dublinbikes* revealing the benefits to substantially outweigh the capital and operational costs (6.4:1 without WEBs to 12.3:1 considering WEBs), making it competitive with major PT investments.

Bikesharing could also mitigate traffic congestion. M. Wang & Zhou (2017) measured its effect on traffic congestions in 96 US urban areas by calculating differences over time (before and after the implementation of bikesharing) and between urban areas with and without BSS, using yearly congestion statistics. M. Wang & Zhou (2017) discovered that in cities without BSS a 1% growth in their population was associated with a 0.6863% increase in congestion, whereas in cities with BSS a 1% increase in the population was associated with 0.0264% less increase in congestion, with a more pronounced effect in larger cities. Hamilton & Wichman (2018) analysed the effect of Washington D.C.'s BSS on congestion by comparing the observed speed to a standard speed in each road segment at the scale of U.S. census block groups. The study reported that the presence of BSS stations in a neighbourhood could lead to reductions in traffic congestion of up to 4% (Hamilton and Wichman, 2018). These congestion reductions may also suggest a modal shift from car to bikesharing, though none of the studies provide direct evidence to support this supposition. Additionally, such aggregated studies are quite prone to potential confounding variables like the introduction of cycling infrastructure which often accompanies the implementation of BSS (Pucher, Dill and Handy, 2010).

Bikesharing may boost local businesses as explored by Buehler & Hamre (2016) in Washington D.C. Through surveying BSS users and local businesses within 0.1 miles of BSS stations, the study found that 70% of businesses felt bikesharing to have had a positive impact in the area, with 59% supporting an expansion of the system and 20% reporting a positive impact on sales. Reciprocally, 23% of BSS users reported spending more as a result of using bikesharing (Buehler and Hamre, 2016). Likewise, assessing the BSS of Minneapolis/Saint Paul, X. Wang, Lindsey, Schoner, & Harrison (2015) identified that the presence of retail businesses was positively associated with BSS trips (for each food-related business, a 1.7% increase in BSS station's trips was observed). However, more accurate metrics, such as comparing retail sales within BSS service areas against overall city trends, are needed to fully assess these possible effects.

BSS also seem to influence housing prices. Controlling for spatial and temporal factors, El-Geneidy, van Lierop, & Wasfi (2016) were able to reveal a 2.7% increase in housing prices in neighbourhoods with *BIXI* stations. This is supported by Pelechrinis, Zacharias, Kokkodis, & Lappas (2017), which analysed the impact of Pittsburgh's BSS on housing and rental values by conducting quasi-experimental techniques and considering both intra-city and inter-city effects. Pelechrinis et al. (2017) revealed an increase in both sales and rental prices of houses located near BSS stations, with significant increases both at the neighbourhood and city levels. While these increases in property values can help to regenerate urban areas, they can also exacerbate inequalities if not carefully considered, potentially leading to gentrification processes, a trend already observed with other cycling policies, namely cycling lanes (Stehlin, 2015).

These appraisals are of special importance as the monetary quantification of the BSS' benefits can not only help to justify public funding (Chow and Sayarshad, 2014; Bullock, Brereton and Bailey, 2017; Yu *et al.*, 2018), but also to gain support from businesses and the public, particularly when the implementation of BSS involves removing car space (e.g., replacing car parking with BSS stations).

2.4. MODAL SHIFT AND CAR REDUCTION

The previous section has shown that shifting car users to bikesharing would contribute to several gains. Now we look at the available literature reporting modal shifts to BSS and, subsequently, its impact in car use. An overview of the multiple studies assessing this relationship, from different geographies, is detailed in Table 5 and summarized in Figure 11.

Table 5 – Reported modal shifts to BSS around the world

Location	Modal Shift						Respondents (n)	Data Source	Year of data collection	Reference
	Car / motorcycle	Taxi	PT	Walking	Own bike	New trip				
Australia										
Brisbane	21%	3%	43%	23%	8%	1%	443	Online survey (P)	2012	Fishman, Washington, & Haworth (2014)
Melbourne	19%	2%	41%	27%	9%	1%	372	Online survey (P)	2012	Fishman, Washington, & Haworth (2014)
China										
Hangzhou	8%	5%	59%	19%	10%	N/A	275	Intercept survey (N)	2009	Tang, Pan, & Shen (2011)
Nanjing	15%	4%	19%	47%	15%	N/A	168	Intercept survey (N)	2013	M. Yang, Liu, Wang, Li, & Zhao (2016)
Europe										
Barcelona (Spain)	10%	N/A	51%	26%	6%	N/A	N/A	Secondary data	N/A	Midgley (2011)
Dublin (Ireland)	3%	N/A	31%	54%	12%	N/A	237	Intercept survey (N)	2011-2012	O'Neill & Caulfield (2012)
	20%	N/A	35%	46%	N/A	N/A	360	Intercept survey (N)	2011	Murphy & Usher (2015)
Lyon (France)	7%	N/A	50%	37%	4%	2%	N/A	Secondary data	N/A	Midgley (2011)
London (UK)	1%	4%	61%	29%	5%	1%	1199	Online survey (P) + Intercept survey (N)	2010	TfL (2011)
	2%	4%	58%	26%	8%	4%	2177		2011	
UK (cross- country)	23%	3%	22%	31%	9%	10%	891	Online survey (N)	2016	bikeplus (2017a)
	13%	3%	28%	33%	12%	10%	649	Online survey (N)	2017	bikeplus (2017b)
	10%	4%	27%	42%	7%	7%	1790	Online survey (N)	2018	Comouk (2018)

Paris (France)	8%	5%	65%	20%	N/A	N/A	N/A	Secondary data	2008	Midgley (2011)
North America										
Minnesota (USA)	19%	3%	20%	38%	8%	9%	681	Online survey (P)	2010	Fishman, Washington, & Haworth (2014)
Montreal (Canada)	2%	8%	33%	25%	28%	4%	1432	Online survey (N)	2010	Bachand-Marleau et al. (2011)
	8%	N/A	50%	18%	24%	N/A	2502	Telephone survey (P)	2009	Fuller, Gauvin, Kestens, Morency, et al. (2013)
	10%	6%	41%	21%	22%	N/A	2509		2010	
Washington D.C. (USA)	7%	6%	45%	31%	6%	4%	5464	Online survey (P)	2012	Fishman, Washington, & Haworth (2014)

P – Probability Sampling; N – Non-Probability Sampling

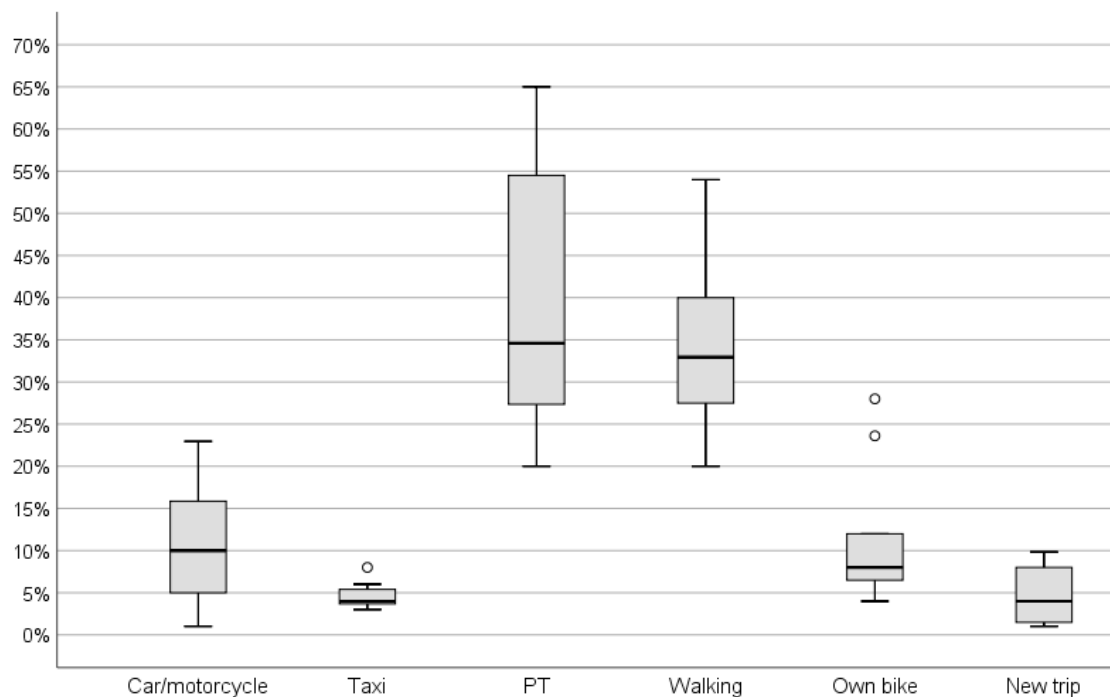


Figure 11 – Boxplots of the reported modal shifts to BSS from the studies of Table 5

Most reported studies have assessed the modal shifts induced by BSS through cross-sectional travel surveys asking BSS users which mode of transport they were replacing. Although with various degrees of representativity, they overwhelmingly indicate that most substituted trips by BSS derive from sustainable modes of transport, with only a small part shifting from car. Of the 19 studies reported in Table 5 and Figure 11, the median percentage of respondents replacing car trips with bikesharing was 10%, whereas the median of replaced trips from public transport or walking was 70%.

Nonetheless, the available results also reveal a high variability in car substitution rates, with systems only capturing a small percentage of car users (e.g., London), whereas others report much higher car modal shifts (e.g., Australia). An explanation is proposed by Fishman, Washington, & Haworth (2014). Compiling survey data from five BSS (London, Brisbane, Melbourne, Minnesota, and Washington D.C.), they hypothesized that cities with higher car modal shares had higher car replacing rates. Brisbane, Melbourne and Minnesota, all heavy reliant on car use, presented the highest modal shifts, whereas London and Washington D.C., with lower car modal shares, presented much lower replacement rates (Fishman, Washington and Haworth, 2014). However, analyses testing this theory and exploring other possible factors are needed.

Further insights are brought out by M. Yang et al. (2016) while examining the mobility patterns of metro-BSS users (commuters combining BSS with metro) in Nanjing. The study revealed that while car was not the most substituted mode, the observed share was higher than the city's average (15.4% versus 12.5%). Moreover, metro-BSS users had considerably higher car-ownership rates than the city's average (48.8% versus 19.7%) (Yang et al., 2016). Likewise, in Hangzhou, BSS members had higher car ownership rates than non-members (Shaheen et al., 2011). Furthermore, even though Hangzhou's system was also mostly replacing PT or walking trips, 78% of car owners stated replacing car trips with BSS (Shaheen et al., 2011). This suggests that bikesharing has features attractive to car users, with car ownership not deterring the propensity for using BSS.

One limitation of the previous studies is that they generally focus on BSS members (monthly/yearly subscriptions), disregarding the travel behaviour of casual users. Buck et al. (2013) present one of the

few studies comparing the travel behaviour of the two groups, through combining an intercept survey of casual users with an online survey of members in Washington D.C. Although BSS was mainly replacing sustainable trips in both groups, casual users predominantly replaced walking (53% versus 31%), whereas members mostly replaced PT (45% versus 35%). Casual users also reported considerably lower replacement rates for car (1% versus 7%) and personal bike (2% versus 6%). This is partially explained by most casual users using bikesharing for tourism, thus not having access to a personal vehicle (Buck *et al.*, 2013).

Additionally, the emergence of e-bikes could induce new modal shift dynamics. A. Campbell *et al.* (2016) presents one of the few studies analysing the potential role of e-bikes in bikesharing (e-bikesharing). The authors employed a SP survey among Beijing residents to estimate their likelihood of switching to conventional bikesharing or to e-bikesharing. Although car replacement was low in both cases, e-bikesharing had a more pronounced impact (6% vs 3%) and would be utilized for longer trips (average of 4.5 km versus 1.5 km). Moreover, the presence of license plate restrictions had little influence on e-bikesharing choice, indicating that car users shifting to e-bikesharing consider it a competitive alternative (Campbell *et al.*, 2016). However, the study was based on stated preferences in a country with heavy restrictions on car use and lower car ownership rates comparing to western countries (US Department of Energy, 2017). Furthermore, large BSS employing e-bikes are few and data on its modal shifts is scarce or non-existent.

Finally, the frequency of the substituted trips is also pertinent to assess the magnitude of car use reductions. Combining O/D surveys with trip data from *BIXI*, Wielinski, Trépanier, & Morency (2017) classified users according to their usage frequency, with most being high-frequency (50.7%), followed by low-frequency (33.1%) and mid-frequency (16.2%) users. Surprisingly, *BIXI* was only the third most preferred mode of transport among the high-frequency users (after PT and walking), being even less significant among mid (4th most used) and low-frequency (5th) users (Wielinski, Trépanier and Morency, 2017). Results from Raux, Zoubir, & Geyik (2017) further underpin that BSS plays a small role on the travel patterns of its users. Analysing the travel behaviour of annual members of *Velo 'v*, the study revealed that only 22% of them used *Velo 'v* as their main mode, being the third choice after PT (30%) and walking (24%). Nonetheless, annual members had considerably lower car usage rates when comparing with Lyon's general population (15% vs 27%), indicating that *Velo 'v* may be replacing car trips (Raux, Zoubir and Geyik, 2017).

Thus, the mobility patterns of BSS users are complex, with evidence exposing that even the most frequent users only consider bikesharing on a small part of their travel routines. Conversely, it also highlights the multimodality of BSS which could indicate potential synergies with other modes of transport. This is discussed in the next section.

2.5. SYNERGIES WITH OTHER MODES

Although the current literature reveals bikesharing to have a modest direct effect in replacing car, BSS could also indirectly impact car use by strengthening other modes. In this section we look at the available evidence of the two main potential synergies with BSS:

- The ability to complement Public Transport (2.5.1.)
- The role in increasing and normalizing cycling (2.5.2.)

2.5.1. COMPLEMENT TO PUBLIC TRANSPORT

Bikesharing can substitute as well as complement PT depending on the circumstances, being associated with increases and decreases in PT usage. An appealing explanation is proposed by Martin & Shaheen (2014) through the analysis of the modal shift dynamics between PT and BSS in Minneapolis and Washington D.C. Martin & Shaheen (2014) argue that bikesharing acts as a substitute mode in high density areas due to being faster and cheaper than PT (which also tends to be overcrowded), while complementing PT in peripheric and low density areas by acting as a first and last mile connector, increasing the catchment areas of less developed PT networks. This theory seems to be supported by X. Ma, Ji, Yang, Jin, & Tan (2018) which, through examining BSS-metro transfer trips in Nanjing by matching metro and BSS smartcards for each passenger, observed most BSS-metro trips to be occurring in suburban areas. Furthermore, K. Campbell & Brakewood (2017), by analysing daily route-level bus and BSS ridership data from New York City, found a decrease in bus ridership in routes with BSS stations in their vicinities. Interestingly, K. Campbell & Brakewood (2017) considered the impact so large they hypothesized that the presence of BSS could also have led PT users to shift to personal cycling due to a more bike-friendly environment. Nevertheless, the hypothesis proposed by Martin & Shaheen (2014) needs to be further validated, especially with case-studies outside the US.

Additionally, higher bikesharing usage rates are often found near major PT stations, particularly rail stations. T. Ma, Liu, & Erdoğan (2015), analysing the relationship between BSS and the metro of Washington D.C found that six of the seven most used BSS stations were close to metro stations. Noland, Smart, & Guo (2016), by deploying trip generation models for BSS in New York, also found BSS stations located near busy subway stations to have amongst the highest usage rates. This relationship is likewise observed by Yuanyuan Zhang & Zhang (2018), finding that a 1% increase in PT ridership would lead to a 4% increase in the probability and to a 1.4% increase in the frequency of BSS usage in all nine US states investigated. Indeed, a proportion of BSS users already combines the two modes in their mobility patterns. Murphy & Usher (2015) revealed that 36% of *Dublinbikes* users were integrating it with PT, which are echoed by the surveys of TfL (2011) demonstrating that between 39% (wave 1) and 41% (wave 2) of respondents used London's BSS as part of a longer trip, mostly combining with PT.

BSS can also increase the transport network's resilience to disruptive events as observed by Saberi, Ghamami, Gu, Shojaei, & Fishman (2018). Measuring the impact of a subway strike on London's BSS, the authors observed that the subway strike led to an 85% increase in the number of BSS trips, increasing the trips' duration by 88% from an average of 23 to 43 min. These findings highlight the potential of BSS complementing PT, in this instance by potentially using BSS to reduce the load of PT networks, which in the case of overcrowded services (such as London's subway) can be of significant value (Saberi *et al.*, 2018).

One of the underlying assumptions for combining the two modes is the potential of reducing overall travel times. Deploying a spatial network model to the BSS of Hangzhou and Ningbo (China), H. Yang *et al.* (2018) discovered that indeed bikesharing could significantly reduce passengers' travel times, especially the average transfer times of bus users. Jäppinen, Toivonen, & Salonen (2013) offer additional evidence by modelling the potential effects of a BSS on Helsinki's PT travel times. Using datasets from the city's PT operator, they compared travel times to major destinations by PT, BSS and the combination of PT and BSS. The study estimated that the BSS implementation could reduce PT access and egress times, on average, by 6 min per trip. However, most gains were concentrated in the periphery, while in the centre near the main PT stations the travel times by PT versus the combination of PT and BSS would remain almost the same (Jäppinen, Toivonen and Salonen, 2013).

Therefore, bikesharing could improve PT networks either by potentially reducing travel times, increasing their catchment areas, or alleviating congested systems. This, in turn, could increase the competitiveness of both modes against car. Delving on this possibility, Shaheen, Martin, & Cohen (2013) asked users of three BSS if they were combining PT and BSS to substitute trips previously made by car. Although modest, users reported combining BSS and PT trips to replace car trips (28% in Toronto, 41% in Montreal and 50% in Minneapolis/Saint Paul) (Shaheen et al., 2013). However, being relatively recent, BSS are still not being fully considered by authorities when planning their transport networks, hindering these possible synergetic gains (Griffin and Sener, 2016). A prime example of BSS and PT integration can be found in the Netherlands' *OV-fiets* system. Albeit more of a hybrid between bikesharing and bike-rental, *OV-fiets* was specifically implemented by the Dutch rail company to increase train ridership, including integrating it with the PT smartcard (Villwock-Witte and van Grol, 2015). The Dutch estimate an increase in bike-train users from 30% to 50%, with users' surveys revealing more than 10% of respondents to be replacing car with multimodal train *OV-fiets* trips (Villwock-Witte and van Grol, 2015).

2.5.2. CYCLING PROMOTION

Bikesharing could play a prominent role in encouraging and normalizing cycling, with studies showing an increase in overall cycling levels after the implementation of a BSS. A broad assessment of *BIXI*, through randomized telephone surveys, revealed the system to be able to attract a significant proportion of Montreal's population (Fuller et al., 2011; Fuller, Gauvin, Kestens, Daniel, et al., 2013). First, Fuller et al. (2011), estimating the prevalence of *BIXI*'s use in Montreal, found that at least 8.2% of the adult population had tried the system. Second, Fuller, Gauvin, Kestens, Daniel, et al. (2013) uncovered that the cycling levels were increasing not only within the system but also regarding personal bikes (both commuting and leisure), especially among people residing in areas with *BIXI* stations. Molina-García et al. (2015) also observed an increase in cycling use from 7% to 11% among university students in Valencia after 8 months of implementing a BSS. Moreover, Murphy and Usher (2015) found that 68.4% of *Dublinbikes*' users did not cycle for their current trip before the system's launch, with 63.4% of respondents reporting to have purchased their own bike as a result of *Dublinbikes*. Further evidence can be uncovered in BSS users' surveys conducted by Transport for London with, for example, in the study conducted after the system's second expansion in 2011, 70% of users reporting to have started to cycle or cycling more due to the BSS (TfL, 2011). Likewise, ridership data from New York City's BSS reveals the system to account for around 10% of all cycling trips in the city, with an average daily ridership of 45,000 trips and 150,000 annual members, although the BSS is still mostly confined to Manhattan and some sections of Brooklyn and Queens (Department of Transportation NYC, 2018).

A citywide cycling increase would bring additional benefits, such as increasing physical activity levels across the population (Bauman et al., 2017) or decreases in air pollution and injury risks from reduced motorized traffic (Rabl and de Nazelle, 2012). Research conducted by Schoner, Lindsey, & Levinson (2017) found mixed results on the BSS ability of inducing cycling within the general population. Applying the Diffusion of Innovation Theory to the BSS of Minneapolis/Saint Paul, Schoner et al. (2017) observed a potential diffusion or "spillover effect" of existing BSS users on membership growth (the presence of BSS users would induce new members to join the system). However, evidence on a spatial relation between the existence of BSS and cycling participation within the broad population was not found. This does not mean that a possible relation does not exist, as Schoner et al. (2017) emphasize, the system was still recent and may not cover a sufficient portion of the city to have measurable effects. Assessments of more mature systems could, thus, lead to better outcomes.

Bikesharing may additionally have a positive impact on the attitudes towards cyclists. Murphy & Usher (2015), surveying *Dublinbikes*' users, found that of the respondents who were also car users (80%), 93.8% declared that using *Dublinbikes* had raised their awareness of cyclists when driving. These findings are further supported by Fishman, Washington, & Haworth (2012), through focus groups (categorized in non or infrequent cyclists, regular cyclists and BSS users) aimed at identifying motivations and barriers for BSS use in Brisbane. Among the findings, the focus group of BSS users reported drivers to be more cautious with them when they were using BSS comparatively when using their personal bikes (Fishman, Washington and Haworth, 2012). Goodman, Green, & Woodcock (2014) address an interesting perspective on how BSS could help normalize cycling in cities with low cycling rates. Starting from the premise that potential cyclists may have reservations due to being perceived as an activity for "sporty people" (Aldred, 2013), they observed the clothing of cyclists across London (BSS users and personal-bike cyclists). The observations revealed BSS users to be much less likely to carry any type of specialist cycling gear like helmets and high-visibility clothes (79% of BSS users wore none), comparatively to personal-bike cyclists (30%) (Goodman, Green and Woodcock, 2014). Such possible differences about how BSS users and personal-bike cyclists are perceived should be further investigated, perhaps via conducting attitudinal surveys to non-users, especially car drivers.

2.6. MAIN RESEARCH FINDINGS AND NEEDS

This review has found evidence on a wide range of potential benefits not just to the BSS users but from a societal standpoint, albeit the magnitude of such benefits is not yet clear and is contingent on several caveats. We present a summary of the findings in Table 6.

Table 6 – Summary of the main impacts of BSS

Category	(Potential) Benefits	Limitations and Risks
Environment	Reductions in GHG and other air pollutants	Contingent on replacing motorized modes (particularly car trips), which needs to be balanced with the emissions from rebalancing and maintenance vehicles and the shared bikes' lifetime
Health	Health gains (from increases in PA levels) outbalance the health risks (from exposure to traffic crashes and air pollution) Possible reductions in obesity levels Traffic injury risk may be lower than cycling in general	Contingent on replacing motorized modes (particularly car trips) or generating new trips Assessments limited to high-income countries Health gains may not occur for all groups (gender and age differences have been found) Dependent on the city's traffic safety conditions and air pollution levels
Social Equity	Affordable, time and cost competitive mode of transport Can decrease the accessibility gap between car-owning and car-less groups	Social disadvantaged groups (who have the most to gain) are systematically under-represented Possible gentrification impacts
Economy	Travel time savings Reductions in traffic congestion Increases in local business sales and housing prices	Aggregate studies on congestion impacts may be confounded by other interventions Studies analysing impacts on local businesses are few and with weak research designs

	Cost-benefit and cost-effectiveness analyses point BSS to be competitive with major PT investments and public health interventions	
Modal Shift and Car Reduction	Reductions in car use	Most replaced trips are from sustainable modes of transport Bikesharing is treated as an auxiliary mode of transport by most users
Synergies with Public Transport	Can enhance PT networks by increasing its catchment areas, reducing overcrowding and overall travel times	Can also be a competitor to PT
Cycling Promotion	Can promote cycling, either directly increasing cycling levels by providing shared bikes or indirectly by increasing the diversity of cyclists and awareness towards cycling	Increases in cycling detected after BSS implementation may be confounded by cycling infrastructure improvements occurring concurrently

Despite of a considerable number of studies devoted to assessing bikesharing, the available evidence on much of its benefits is still scarce and patchy, with a limited number of high-quality studies available. Most of the studies employed cross-section designs, with few utilizing experimental designs with before-and-after measurements and control groups. A common need to several of the assumed benefits is accurate data on the modes being replaced and trips being generated, as well as the frequency and distance of those trips. While the frequency and distance can be directly obtained from the systems themselves (most modern BSS now collect GPS data, although it can be difficult to obtain due to data protection issues), mode shift is hard to measure. Most studies ask BSS users about the most common BSS trip and which mode they were using before shifting to BSS or what mode would they use if BSS was not available. Although these surveys are useful, they are very dependent on the point in time when the survey was performed and may be prone to self-report bias. Conducting annual or seasonal (representative) surveys to the BSS users regarding their modal shift dynamics could minimize some of these limitations by revealing the overall trends throughout the years. In here, a combination of online surveys to BSS members (as most members need to provide an email for contact) with intercept surveys of casual users (a more elusive group), may be the best option to ensure a representative sample.

An (resource intensive) alternative approach would be employing large-scale longitudinal studies at the population-level such as travel diaries of a randomized number of potential users before and after the BSS implementation (or expansion to a new area). Besides providing a clearer picture on the modal shift impacts of bikesharing at the city-level (including in non-users), such assessments would allow to quantify its broad impacts, encompassing possible population-level cycling increases and health gains. The incorporation of a section dedicated to BSS in already established citywide surveys, such as census or representative panel surveys, could be a practical solution. However, this kind of procedure only makes sense in cities with large scale BSS encompassing sizable sections of the city, otherwise population-level effects will be residual or inexistent. In that sense, the Chinese BSS, which are the largest systems in operation (Qiu and He, 2018; Nikitas, 2019), are prime candidates especially regarding possible health impacts as current evaluations are limited to western countries. Another data source that can be helpful to estimate BSS' impacts is bike counts. Bike counts in strategic city locations before and after the implementation of a BSS would help to better gauge the true BSS impact in a city's cycling levels. In order to minimize the influence of other cycling interventions, which often occurs parallelly with BSS deployments (Pucher, Dill and Handy, 2010), manual counts distinguishing between

personal and shared bikes (which tend to be easy to identify) may minimize such bias as attested in a recent study (Félix, Cambra and Moura, 2020).

This research has also established that enhancing the attractiveness of BSS to car users would increase several of its benefits, namely reductions in GHG and air quality improvements, increases in PA, time savings as well as congestion decreases. However, the current literature reveals modest car replacing rates, with most substituted trips coming from sustainable modes of transport. Nevertheless, BSS can reduce car use, with the substitution rates varying across the systems, although the factors leading to these differences are not fully identified and need further enquiry. This reduction in car use, even if small, should not be disregarded as modal shift from car has been shown to be particularly difficult, with most available initiatives revealing modest results (Ogilvie *et al.*, 2004).

Modal shift from other modes can still lead to benefits. For instance, modal shift from walking to BSS, although potentially causing negative health/environmental impacts, has also been associated with time saving benefits which can be especially important for lower-income groups. Likewise, new cycling trips generated by BSS would increase PA levels as well, inducing health benefits. Furthermore, for cities with overcrowded PT services a BSS could alleviate some of the pressure for a fraction of the cost of expanding PT networks.

Additionally, bikesharing possesses potential advantages that could be exploited to induce further car modal shift. Firstly, BSS can be as fast or even faster than cars in dense urban areas, with former car drivers citing longer travel times, congestion, difficulty in finding a parking space and higher costs as reasons for shifting to bikesharing (Yang *et al.*, 2016). Secondly, with environmental and health concerns gaining relevance among the population, marketing the bikesharing's sustainability and health credentials could further induce car modal shifts. Environment and health concerns are already among the main reasons stated by BSS users for switching to BSS (TfL, 2011; Fishman *et al.*, 2014; TfL, 2018), with the perception of environmental and health benefits positively influencing intentions to use BSS among non-users (Chen and Lu, 2016; Kim *et al.*, 2017).

Besides, new innovations such as *dockless* systems and e-bikes could induce different modal shifts but have not been properly investigated. For instance, e-bikes offer new advantages from its capacity to help overcoming hilly terrains to its increased range, which can facilitate possible BSS expansions to more peripheral areas. This is especially relevant as most BSS are still concentrated in the city centres, which tend to have lower car modal shares (Murphy and Usher, 2015). Thus, studies comparing the performance between conventional docked BSS and these new systems, either *dockless* or e-bikesharing, are needed not only regarding modal shifts but other impacts such as equity of access.

Moreover, coordinating investments in cycling infrastructure with the implementation of BSS may increase the competitiveness of cycling against car. The provision of dedicated cycling infrastructure addresses one of the main barriers preventing BSS use - safety concerns (Fishman, 2016). Increasing the safety of BSS use would also improve the health benefits for the most vulnerable groups such as women (Woodcock *et al.*, 2014), possibly also inducing higher uptakes. Indeed, in the Netherlands where cycling injury rates are amongst the lowest in the world, women cycle as often as men (Pucher and Buehler, 2008). Equally, BSS has been shown to increase cycling levels, including personal cycling. As such, the conjugation of the two policies could create a virtuous cycle where the supply of dedicated cycling infrastructure fosters the conditions for BSS use and an increase in BSS ridership fuels the demand for additional cycling investment.

Lastly, BSS can not only directly compete with car but also induce indirect reductions through synergies with other modes (Figure 12). Car trips can be directly replaced by BSS trips or through a combination of BSS and PT trips (with BSS acting as a first and last mile connector). Furthermore, by increasing

both the number and diversity of cyclists, bikesharing can not only help to normalize cycling use but also increase its safety, inducing shifts to personal bikes. Additionally, BSS can alleviate congested PT networks, which in turn might increase the attractiveness of PT to car users.

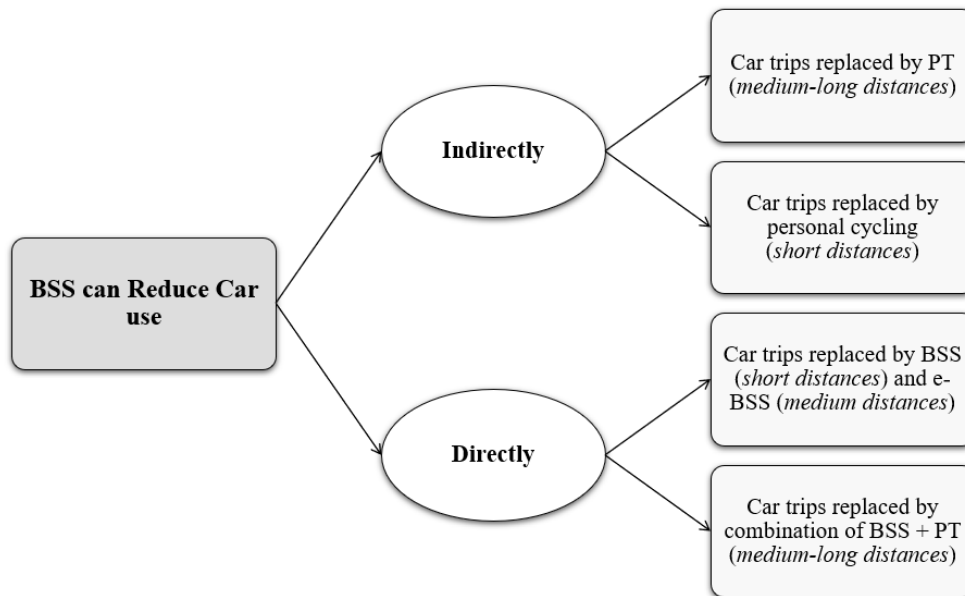


Figure 12 – The possible modal shifts from car due to BSS' influence

But major barriers persist. Dangerous traffic conditions and lack of dedicated cycling infrastructure hinder the possibility of larger swaths of the population to join BSS. Vandalism and the use of motor vehicles in rebalancing operations also reduce the sustainability of BSS. Furthermore, one could question if the public funds allocated to BSS wouldn't produce better outcomes if instead allocated to cycling infrastructure as defended by Médard de Chardon (2016). However, the fact is that thousands of BSS are already in operation across the globe with its current users finding benefits. Consequently, and considering the significant benefits of reducing car use highlighted throughout this review, researchers and practitioners should focus on the potential of bikesharing to provide an effective alternative to car use, either directly or through synergies with other modes of transport. Such efforts could not only improve BSS' performance in replacing car travel but also enhance BSS' ability to provide car-less groups with a competitive (and affordable) transport alternative.

3.

THE POTENTIAL OF BIKE SHARING DURING DISRUPTIVE PUBLIC HEALTH CRISES: A REVIEW OF COVID-19 IMPACTS AND POLICY RESPONSES

This chapter presents a partial reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (2023) ‘Potential of Bike Sharing During Disruptive Public Health Crises: A Review of COVID-19 Impacts’, Transportation Research Record. SAGE, 0(0). doi: 10.1177/03611981231160537”

ABSTRACT

With public transport (PT) continuing to be negatively affected by the coronavirus pandemic and private car usage surging, alternative modes need to be considered. In this study, we review the available evidence (from academic and grey literature sources) on the performance of bike sharing systems (BSS) during COVID-19 around the world, with the goal of assessing their potential contribution in improving the resilience of transport systems towards pandemics and similar disruptive events.

We found BSS usage to follow a decrease-rebound pattern, with BSS overall sustaining lower ridership declines and faster recoveries when compared with PT. Especially during lockdowns, the average duration of BSS trips has increased, following a rise in casual users and leisure trips, while commuting trips have decreased. Evidence has also been found on a possible modal shift from some PT users to BSS, with a decline in the share of multimodal trips conducted between PT and BSS. Bike sharing is perceived as safer than other shared modes (PT, taxis and ride-hailing/sharing) but as having a higher infection risk than personal modes (private car, walking and personal bike). Moreover, BSS was an important transport alternative for essential workers, with several operators providing waivers especially to healthcare staff, leading to ridership increases near healthcare facilities and in deprived neighbourhoods.

Assessing the ability of bike sharing in increasing the sustainability and resilience of transport systems, particularly under the scenario in which coronavirus continues to be a threat and PT ridership remains below pre-pandemic levels, should be a research priority.

KEYWORDS: Bike sharing; Coronavirus; Impacts; Policy responses; Resilience

3.1. INTRODUCTION

Since its emergence, the coronavirus pandemic has caused incalculable damage across the world. More worrying, even after the administration of billions of vaccine doses, COVID-19 continues to unleash havoc, with infection rates systematically surging even in countries with high vaccination and booster rates. As such, societies start to cope with the realization that coronavirus may be here to stay (Nature, 2022).

The ever more likely scenario of coronavirus becoming endemic has profound consequences (Sharifi and Khavarian-Garmsir, 2020; Nature, 2022), particularly regarding mobility, with transport being one of the most affected sectors by the pandemic (Sharifi and Khavarian-Garmsir, 2020). Public transport (PT) in particular, has been greatly impacted by coronavirus, suffering record-breaking ridership drops (Gkiotsalitis and Cats, 2020), which are still far from recovering two years after the beginning of the pandemic (APTA, 2022). The potential permanent ridership loss of PT has severe repercussions, namely concerning the pressing need for decarbonization (IPCC, 2022). Indeed, the transport sector is responsible for around one quarter of all CO₂ emissions (Rogelj *et al.*, 2018), of which car travel is the main source (Graham-Rowe *et al.*, 2011). Moreover, the increasing fuel prices registered across the world are making car travelling more expensive (euronews, 2022), exacerbating transport inequalities (Lucas *et al.*, 2016). Thus, and with one of the best sustainable alternatives to car usage suffering the prospect of a long-term decline, additional modes of transport are urgently needed.

Amongst the potential alternatives to PT and car use are bike sharing systems (BSS). Characterized by providing low-cost short-term renting of bikes, either at stations (docked BSS) or within operational areas (free-floating or dockless BSS), BSS have rapidly increased in popularity, with systems currently operating in more than 1000 cities across the world (Meddin Bike-sharing World Map, 2021). Bike sharing has already been shown to be a travel time and cost competitive mode, capable of complementing PT and reducing car usage (Teixeira, Silva and Moura e Sá, 2021a). Furthermore, by avoiding the ownership inconveniences associated with a personal bike (i.e., cost, secure parking and greater trip flexibility), BSS have the potential to increase cycling usage rates at the city level (Teixeira, Silva and Moura e Sá, 2021a), being, for instance, associated with reversing the cycling decline in China (Mobike, 2017). Importantly, BSS has already been shown before COVID-19 to increase the resilience of transport systems by providing an alternative mode during subway strikes (Saber *et al.*, 2018).

Hence, it is paramount to understand how COVID-19 has affected the operation of bike sharing systems in order to gauge their potential contribution to increase the resilience and sustainability of urban transport systems, particularly during disruptive public health crises. As such, the main objective of this study is to review and synthesize the available research published during the first two years of the coronavirus pandemic concerning bike sharing, seeking to answer the following questions:

- *What were, so far, the main impacts of COVID-19 on bike sharing?*
- *How have BSS performed comparatively to other modes during the pandemic?*
- *What type of measures related to BSS have operators and public authorities implemented as a response to coronavirus?*

The article is structured as follows. Next, the main employed literature search strategy (including searched databases, selection criteria and keywords used) is detailed (section 3.2.). This is followed by the presentation of the COVID-19 impacts on BSS (section 3.3.). Next, the policy responses adopted during COVID-19 and affecting BSS are reported (section 3.4.). The study ends with the main research findings and needs as well as their policy implications, providing recommendations for policymakers on how to develop transport systems more resilient to pandemics by taking advantage of BSS (section 3.5.).

3.2. METHODOLOGY

The selection of the studies included in this review involved three distinct stages (Figure 13). We started by searching for academic literature (articles published in peer-reviewed journals and conference papers with peer-reviewed proceedings) in Scopus, Web of Science (WoS) and the Transport Research International Documentation (TRID) databases, using search word combinations of bike sharing and COVID-19⁴. Next, due to the coronavirus novelty coupled with the lengthy process until a peer-reviewed article is published, we also examined grey literature from BSS operators, public agencies, intergovernmental organizations (IGOs) as well as news agency websites. Lastly, backward snowballing was conducted in both sets of data sources. As inclusion criteria, the studies had either to analyse impacts of COVID-19 on bike sharing or report on measures adopted as a response to the pandemic that directly affected BSS. Additionally, secondary data on BSS and PT ridership was also collected directly from operators' websites⁵.

The literature was collected between December 29th 2021 and March 31st 2022, being limited to studies written in English. The initial selection generated a total of 87 studies (55 peer-reviewed and 32 grey literature sources), with the final number of studies included in the review decreasing to a total of 58 (39 peer-reviewed and 19 from grey literature). Most studies were published in 2021 and refer to the first COVID-19 wave of 2020. The review includes studies from across the world, mainly Europe (particularly from the UK, Italy, Switzerland, Greece and Portugal), North America (mostly the US) and Asia (especially China and South Korea). Furthermore, the majority of peer-reviewed studies evaluated the COVID-19 impacts on BSS, with most research analysing ridership data provided by the BSS operators, sometimes coupled with data from open access sources such as land use, POI (points-of-interest), COVID-19 cases as well as ridership from other modes of transport like PT. A few peer-reviewed studies conducted travel behaviour surveys either aimed at the general population in which bike sharing was one of the modes evaluated or specifically targeted at BSS users. Conversely, most grey literature focused on the measures implemented during COVID-19 by either operators or public authorities that affected BSS.

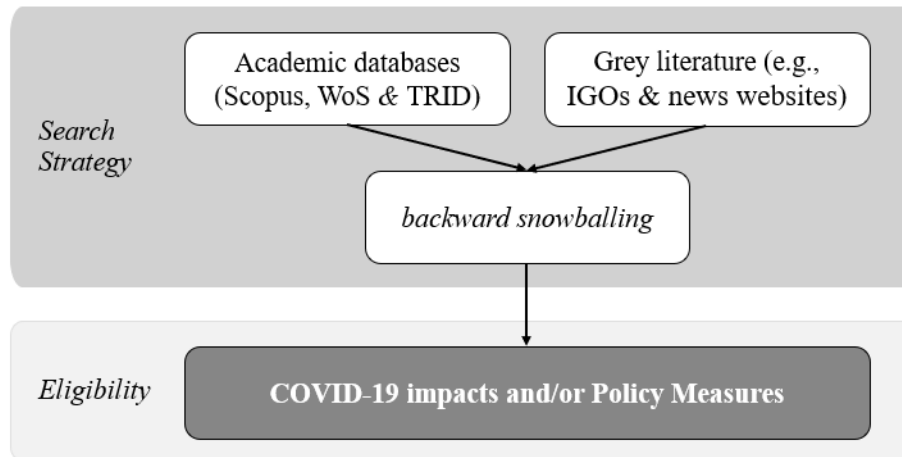


Figure 13 – Diagram of the literature search strategy employed

⁴ For the Scopus and WoS databases the specific search terms used were: ("coronavirus" OR "COVID-19" OR "Covid 19" OR "covid19" OR "SARS-CoV-2") AND ("bike sharing" OR "bicycle sharing" OR "bike share" OR "bikeshare" OR "shared bicycle*" OR "bikesharing" OR "shared bike*" OR "public bicycle*" OR "public bike*").

⁵ We searched for cities in which ridership data on both BSS and PT during COVID-19 was available in English. In total, six case-studies, all from North America, were included (Figure 14).

3.3. COVID-19 IMPACTS

We divided the main COVID-19 effects on bike sharing into six categories: ridership; length and duration of trips; trip purposes and travel patterns; relationship with public transport; profile of BSS users; and attitudes. We start by presenting the main findings in Table 7. Each category is then explored in depth in the following subsections.

Table 7 – Summary of the main COVID-19 impacts

Category	Main Findings	References
<i>Ridership</i>	BSS ridership during COVID-19 followed a decrease-rebound pattern, with ridership severely declining during lockdowns, but quickly recovering when mobility restrictions are lifted, reaching and even surpassing pre-pandemic levels. Comparatively to other modes BSS has generally sustained lower ridership drops and faster recoveries, particularly when compared with PT systems	(Bucsky, 2020; Orro <i>et al.</i> , 2020; Park, Kim and Lee, 2020; Teixeira and Lopes, 2020; Tokey, 2020; H. Li <i>et al.</i> , 2021; Wang and Noland, 2021; Hu <i>et al.</i> , 2021; Lei and Ozbay, 2021; Shang <i>et al.</i> , 2021; Theresa Firestone, 2021; Teixeira, Silva and Moura e Sá, 2022a)
<i>Length and duration of trips</i>	The average distance and duration of BSS trips have increased, especially during lockdowns	(Teixeira and Lopes, 2020; Kubaľák, Kalašová and Hájnik, 2021; Wang and Noland, 2021; H. Li <i>et al.</i> , 2021; Hu <i>et al.</i> , 2021; Hua <i>et al.</i> , 2021; A. Li <i>et al.</i> , 2021; Padmanabhan <i>et al.</i> , 2021; Shang <i>et al.</i> , 2021; Bouhouras <i>et al.</i> , 2022; Wendong Chen <i>et al.</i> , 2022; Dastjerdi and Morency, 2022)
<i>Trip purposes and travel patterns</i>	Overall increase in the share of leisure trips, while commuting trips have fallen. Residential and outdoor areas (such as parks) have increased in popularity	(NABSA, 2020; Pase <i>et al.</i> , 2020; A. Li <i>et al.</i> , 2021; H. Li <i>et al.</i> , 2021; Hu <i>et al.</i> , 2021; Hua <i>et al.</i> , 2021; Kim, 2021; Lei and Ozbay, 2021; Padmanabhan <i>et al.</i> , 2021; Dastjerdi and Morency, 2022; Song <i>et al.</i> , 2022)
<i>Relationship with Public Transport</i>	Change on the relationship between BSS and PT from complementarity to competitiveness, with a decline in the share of BSS+PT multimodal trips and evidence of a possible modal shift from PT to BSS	(comouk, 2020; Pase <i>et al.</i> , 2020; Teixeira and Lopes, 2020; Hu <i>et al.</i> , 2021; Ku <i>et al.</i> , 2021; Scorrano and Danielis, 2021; Teixeira, Silva and Moura e Sá, 2022a; Wendong Chen <i>et al.</i> , 2022)
<i>Profile of BSS users</i>	The share of casual users has increased, while long-term members have declined. Bike sharing was sought after by essential workers as a transport alternative during COVID-19, with ridership increases in BSS stations near healthcare facilities and in deprived neighbourhoods	(City Monitor, 2020; Pase <i>et al.</i> , 2020; H. Li <i>et al.</i> , 2021; Hu <i>et al.</i> , 2021; Hua <i>et al.</i> , 2021; Lei and Ozbay, 2021; Padmanabhan <i>et al.</i> , 2021; Tiako and Stokes, 2021; Wang and Noland, 2021; Wendong Chen <i>et al.</i> , 2022)
<i>Attitudes</i>	BSS is perceived as having a lower infection risk than other shared modes (PT, taxi and ride-hailing/sharing) but riskier than using personal modes (private car, walking and personal bike). Increase on the importance of using BSS to avoid PT and for social distancing	(comouk, 2020; CUTR, 2020; Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour <i>et al.</i> , 2020; Bergantino, Intini and Tangari, 2021; Ceccato, Rossi and Gastaldi, 2021; Esposti, Mortara and Roberti, 2021; Teixeira, Silva and Moura e Sá, 2021b, 2022a)

3.3.1. RIDERSHIP

BSS ridership during the coronavirus pandemic seems to follow a *decrease-rebound* pattern. Like most modes of transport, BSS usage rapidly plummeted when the number of COVID-19 cases started to increase and restrictions on mobility were implemented (Bucsky, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021; Shang *et al.*, 2021). For instance, the BSS of New York City (USA), entitled *Citi Bike*, registered a 71% ridership drop by the end of March 2020 comparatively to pre-pandemic levels registered early in the month (Teixeira and Lopes, 2020; Wang and Noland, 2021). Likewise, in Beijing (China) COVID-19 provoked a 65% ridership reduction in the city's BSS from January 1st to March 1st 2020 in comparison to the same period in 2019 (Chai *et al.*, 2021). However, after the number of COVID-19 cases starts to fall and mobility restrictions are gradually lifted BSS usage quickly recovers (Orro *et al.*, 2020; Tokey, 2020; H. Li *et al.*, 2021; Hu *et al.*, 2021; Theresa Firestine, 2021; Wang and Noland, 2021; Teixeira, Silva and Moura e Sá, 2022a), with in several case-studies reaching (CDRC, 2020; Hu *et al.*, 2021; Wang and Noland, 2021), and sometimes even surpassing (Park, Kim and Lee, 2020; Ku *et al.*, 2021) pre-pandemic ridership levels. For instance, taking the previous case-study of New York City, *Citi Bike* ridership started to improve in early April, fully recovering its ridership levels comparatively to 2019 by September 2020 (Wang and Noland, 2021). Meanwhile, in Seoul (South Korea), which never implemented a full lockdown, the daily ridership of the city's public BSS between January and March 2020 was double the values registered for the same period in 2019 (Park, Kim and Lee, 2020).

More remarkably, evidence suggests that BSS have sustained lower ridership drops and faster recoveries when compared with other modes, particularly to PT (Bucsky, 2020; Orro *et al.*, 2020; Pase *et al.*, 2020; Teixeira and Lopes, 2020; Chang, Meyerhoefer and Yang, 2021; Hu *et al.*, 2021; Hua *et al.*, 2021; Theresa Firestine, 2021; Wang and Noland, 2021) but also in some cases to private car (Hu *et al.*, 2021; Ku *et al.*, 2021), taxis (Lei and Ozbay, 2021), walking (Hu *et al.*, 2021), personal cycling (Bucsky, 2020) and e-scooter sharing (NABSA, 2020). For example, using as case-study the city of Chicago (USA), Hu *et al.* (2021) assessed the traffic levels of the city's BSS (named *Divvy*), PT, driving and walking between March and July 2020 comparatively to a baseline volume on January 13th 2020 (pre-pandemic). The authors found *Divvy* to register the "highest recovery speed and greatest recovery magnitude" of all modes, with BSS ridership reaching 284% in July 2020, while for the same period driving and walking had increased 137.5% and 131.6%, respectively. In contrast, PT was still 45.8% of the baseline volume in July 2020 (Hu *et al.*, 2021). These findings are supported by Ku *et al.* (2021), which conducted a similar study in Seoul. The authors found that while both PT and car usage have decreased as COVID-19 cases surged, BSS ridership had actually increased, registering on June 2020 a 121% ridership level comparatively to 2019 while car and PT levels were 100% and 71.5%, respectively (Ku *et al.*, 2021). Similarly, in Nanjing (China), while during lockdown metro ridership fell 95% comparatively to pre-pandemic levels, the city's docked and dockless BSS dropped 72% and 82%, respectively (Hua *et al.*, 2021). Additional evidence can again be found in New York. While at the height of the first COVID-19 wave in March 2020, *Citi Bike* was suffering a 71% ridership drop (Teixeira and Lopes, 2020; Lei and Ozbay, 2021; Wang and Noland, 2021), the subway system had a 91% drop (Teixeira and Lopes, 2020; Wang and Noland, 2021) while the city's yellow taxi service declined 96% (Lei and Ozbay, 2021). Moreover, after the lockdown easing on June 2020, BSS ridership drop had decreased to 28% (fully recovering during the month of September 2020) while the subway and taxi services were still suffering, respectively, from a 83% and 94% ridership decline (Lei and Ozbay, 2021; Wang and Noland, 2021). In fact, Lei and Ozbay (2021) reveal that while before COVID-19 the number of taxi trips was much higher than *Citi Bike*, during the pandemic *Citi Bike* has actually surpassed taxi ridership, with the gap continuing to widen until the end of the study (June 2020).

We further explored the resilience of BSS to the coronavirus pandemic by assessing the difference on the average monthly ridership of six BSS in North America (Boston, Chicago, New York City, San Francisco, Toronto and Washington D.C.) throughout 2020 and 2021 comparatively to 2019, comparing it with the cities' PT systems. The aggregated results for the six cities are presented in Figure 14 (disaggregated values for each city are provided in Appendix A6). We can observe that the ridership of both BSS and PT drastically declined during the first COVID-19 wave, reaching a nadir during April 2020, with ridership levels starting to recover after this initial wave, although with further ridership drops during the next waves but with lower magnitudes. However, the graph also reveals that the ridership changes of BSS are always more positive than the corresponding PT. More importantly, while in March 2021 BSS ridership had already fully recovered comparatively to 2019 and remained above pre-pandemic levels throughout the rest of the year, PT never recovers with its average ridership in December 2021 still only 56% of 2019 levels.

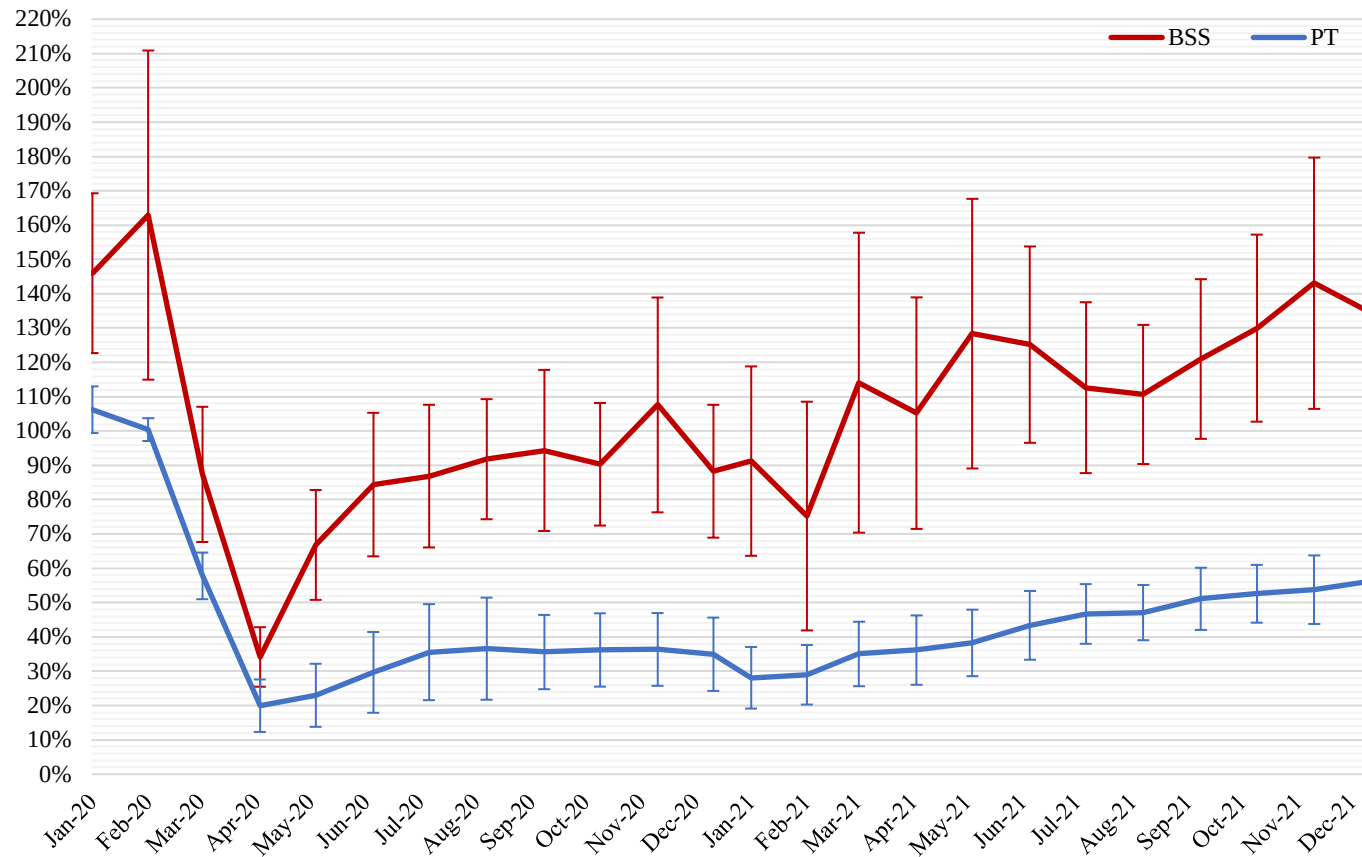


Figure 14 – Difference on the average monthly ridership for BSS (red) and PT (blue) throughout 2020 and 2021 comparatively to 2019 in six North American cities (Boston, Chicago, New York City, San Francisco, Toronto and Washington D.C.). Error bars represent standard deviations. Ridership obtained from operators' publicly available databases in each city⁶

⁶ Boston (BSS: <https://www.bluebikes.com/system-data>; PT: <https://mbta-massdot.opendata.arcgis.com/search?tags=ridership>); Chicago (BSS: <https://ride.divvybikes.com/system-data>; PT: <https://www.transitchicago.com/data/>); New York City (BSS: <https://ride.citibikenyc.com/system-data>; PT: <https://new.mta.info/coronavirus/ridership>); San Francisco (BSS: <https://www.lyft.com/bikes/bay-wheels/system-data>; PT: <https://www.sfmta.com/reports/muni-ridership-average-weekday-ridership>); Toronto (BSS: <https://ckan0.cf.opendata.inter.prod-toronto.ca/tr/dataset/bike-share-toronto-ridership-data>; PT: <https://open.toronto.ca/dataset/toronto-s-dashboard-key-indicators>); Washington D.C. (BSS: <https://ride.capitalbikeshare.com/system-data>; PT: <https://www.wmata.com/initiatives/ridership-portal/>). Websites consulted on April 1st 2022.

3.3.2. LENGTH AND DURATION OF TRIPS

The average distance and duration of BSS trips have generally increased during COVID-19, particularly during lockdowns, with an increase in the share of long trips while the share of short trips has declined. In London, during the first full lockdown, H. Li *et al.* (2021) noticed that the city's BSS ridership fell significantly except regarding its long duration trips (trips longer than 30 to 60 min), while Shang *et al.* (2021) observed in Beijing during the lockdown the BSS trip average duration to increase from 22.5 min to 26.5 min. Likewise, in New York City, *Citi Bike's* average trip duration increased from a 12-13 min to a 19-20 min daily average by the end of March 2020 (Pase *et al.*, 2020; Teixeira and Lopes, 2020), with the ratio of long duration trips doubling (Wang and Noland, 2021), consistently staying above 2019 levels for the rest of the year (Padmanabhan *et al.*, 2021; Wang and Noland, 2021). Similar trends were observed in Boston (Padmanabhan *et al.*, 2021), Chicago (Hu *et al.*, 2021; Padmanabhan *et al.*, 2021), Greece (Bouhouras *et al.*, 2022), Košice (Slovakia) (Kubalák, Kalašová and Hájnik, 2021), Montreal (Canada) (Dastjerdi and Morency, 2022), Nanjing (Hua *et al.*, 2021; Wendong Chen *et al.*, 2022), Seoul (Kim, 2021) and Zurich (Switzerland) (A. Li *et al.*, 2021). There are two main reasons behind this increase in the duration/length of the BSS trips which will be explored in depth in the next two subsections: on the one hand an increase in leisure trips (subsection 3.3.3.), and on the other hand a possible modal shift from some PT users to bike sharing (subsection 3.3.4.).

3.3.3. TRIP PURPOSES AND TRAVEL PATTERNS

COVID-19 has impacted the purpose of BSS trips with an overall increase in leisure trips and a reduction in commuting trips. Several findings support this assertion. Firstly, BSS trips conducted during non-working days were less affected than those conducted during weekdays (NABSA, 2020; A. Li *et al.*, 2021; Hu *et al.*, 2021; Hua *et al.*, 2021; Padmanabhan *et al.*, 2021). For example, in Chicago while before COVID-19 most *Divvy* trips were conducted on weekdays, during the pandemic that trend has shifted with weekends now registering greater ridership levels (Hu *et al.*, 2021). A similar pattern of increased usage on weekends was also observed in Nanjing (Hua *et al.*, 2021) as well as in New York City, where weekend BSS ridership surpassed 2019 levels (Lei and Ozbay, 2021). Secondly, while before COVID-19 BSS travel patterns were characterized by a two-peak (morning and evening) daily commuting pattern, the pandemic has provoked a decline in those peaks (A. Li *et al.*, 2021; H. Li *et al.*, 2021; Hu *et al.*, 2021; Hua *et al.*, 2021; Dastjerdi and Morency, 2022), with in some cases changing to a one peak leisure pattern (Hu *et al.*, 2021). Thirdly, the number of round-trips (trips that start and end at the same BSS station) has increased with, for instance, the share of round-trips of Chicago's *Divvy* more than tripling from 4.7% to 12.7% (Hu *et al.*, 2021).

The increase in the leisure-oriented nature of bike sharing during coronavirus is further supported by changes in the main origins and destinations of BSS trips, with the share of trips near residential and outdoor areas increasing (A. Li *et al.*, 2021; Hu *et al.*, 2021; Kim, 2021; Song *et al.*, 2022). For instance, A. Li *et al.* (2021), through analysing GPS trip data from 3,700 users of both docked and dockless bike sharing in Zurich, found the share of BSS trips near residential areas as well as grocery shops and outdoor activities (such as parks) to increase for all types of BSS while the share of trips near workplaces declined. Similarly, in Chicago, *Divvy* stations near residential areas and outdoor activities suffered lower ridership decreases during the lockdown and recovered earlier than other stations (Hu *et al.*, 2021). Additional COVID-19 impacts on the O/D of BSS trips were identified. BSS stations located in the city centres have experienced higher ridership drops, while stations located in peripheral zones were less affected (Pase *et al.*, 2020; A. Li *et al.*, 2021; Hu *et al.*, 2021), which can be attributed to a reduction in the travel demand both to commuting and other activities that were heavily restricted during COVID-

19. Changes in BSS trips near PT stations were also observed but with conflicting reports. While in both London (H. Li *et al.*, 2021) and Seoul (Kim, 2021) a decrease in BSS trips near PT stations was observed, in Chicago areas with higher PT ridership were found to have lower BSS ridership reductions (Hu *et al.*, 2021). Regardless, in both cases these results seem to indicate a decrease in BSS commuting trips conducted in combination with PT either as a result of stay-at-home orders and/or due to BSS users replacing multimodal BSS+PT trips with using bike sharing on the whole journey. The next subsection will explore in depth the COVID-19 impacts on the relationship between BSS and PT.

3.3.4. RELATIONSHIP WITH PUBLIC TRANSPORT

Previous subsections have already shown BSS to be more resilient than PT with lower ridership drops during stay-at-home orders and faster recovery rates when mobility restrictions are lifted (subsection 3.3.1.). In here, we further explore how COVID-19 has affected the relationship between bike sharing and public transport.

The pandemic seems to have accentuated the relationship of competitiveness between BSS and PT. Before COVID-19, bike sharing was an important feeder to PT (Teixeira, Silva and Moura e Sá, 2021a), particularly rail transport (Martin and Shaheen, 2014; Ma, Liu and Erdoğan, 2015; Noland, Smart and Guo, 2016), while at same time also capable of replacing PT trips (Teixeira, Silva and Moura e Sá, 2021a) including during disruptive events such as PT strikes (Saber *et al.*, 2018). With the emergence of the pandemic, modal shift from PT to BSS seems to have intensified (Pase *et al.*, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021; Ku *et al.*, 2021; Scorrano and Danielis, 2021; Teixeira, Silva and Moura e Sá, 2022a; Wendong Chen *et al.*, 2022). For example, in New York City, Teixeira and Lopes (2020) found the ridership ratio of subway/BSS during March 2020 to decrease more significantly inside the subway's catchment areas. This coupled with an increase in *Citi Bike*'s average trip duration (even during weekdays) points to a possible modal shift from some subway users to the BSS (Teixeira and Lopes, 2020). Furthermore, Pase *et al.* (2020) noted that while subway ridership fell uniformly throughout all of New York City's boroughs, *Citi Bike* ridership in some boroughs actually increased during March 2020 particularly in the BSS stations alongside subway lines. Such findings are supported by Ku *et al.* (2021), which estimated that the modal share of BSS in Seoul has increased from 0.3% to 0.5%, while the modal share of metro-rail declined from 1.3% to 0.9% as of June 2020.

Further evidence can be found in two surveys conducted to BSS users in 2020. First, a cross-country survey aimed at users of UK's bike sharing systems found 29% of respondents reporting to use BSS as an alternative to PT due to COVID-19 (comouk, 2020). Second, a similar survey conducted to BSS users in Lisbon (Portugal) revealed that PT had been surpassed by *GIRA* (the name of the BSS) as their main mode of transport, with now 71% of respondents considering using *GIRA* to avoid PT as an important or very important motivation (versus 48% before COVID-19) (Teixeira, Silva and Moura e Sá, 2022a). Interestingly, Teixeira, Silva and Moura e Sá (2022) also explored *GIRA*'s modal shift dynamics by asking the respondents which mode of transport would they use if the BSS was not available to them both before and during COVID-19. The survey revealed that even though PT was the most replaced mode in both periods its share had actually decreased (while the share of replaced private car, walking and personal bike had increased). Such results led the authors to hypothesize that some respondents no longer considered PT as a transport alternative due to infection fears and would now choose other modes of transport if the BSS was not available (Teixeira, Silva and Moura e Sá, 2022a). We will further explore this issue by delving on the attitudes and motivations of BSS users in subsection 3.3.6.

Concurrently, a number of studies have found evidence of a decline in the share of multimodal trips conducted between BSS and PT, while the share of BSS single trips has increased (comouk, 2020;

Teixeira, Silva and Moura e Sá, 2022a; Wendong Chen *et al.*, 2022). Both previously mentioned surveys found BSS users to reduce combining BSS with PT. In the UK's survey the percentage of BSS trips conducted in combination with bus and train decreased from 23% and 35% to 9% and 10%, respectively (comouk, 2020), while in Lisbon the share of BSS+PT trips declined from 24.9% to 17.2% (Teixeira, Silva and Moura e Sá, 2022a). These results are further supported by Chen *et al.* (2022) which, through using smart card data in Nanjing, found that the share of BSS-metro commuters had decreased from 43.6% to 36.1%. Such reduction in the share of multimodal trips between the two modes, accompanied by an increase in BSS single trips, further support the change on the relationship between BSS and PT from complementarity to competitiveness.

3.3.5. PROFILE OF BSS USERS

Several authors have observed a reduction in the share of long-term BSS members (defined as BSS users with a monthly/yearly subscription), while the share of casual users has increased (Hu *et al.*, 2021; Lei and Ozbay, 2021; Padmanabhan *et al.*, 2021; Wang and Noland, 2021). For example, in Chicago the share of trips conducted by Divvy members declined from 75% in 2019 to 56% in 2020, while the share of trips conducted by casual users significantly increased from 25% in 2019 to 44% in 2020 (Hu *et al.*, 2021). As casual users tend to be more associated with using bike sharing for leisure purposes while BSS members are more connected to commuting trips, such findings further support the previously discussed increase on BSS leisure-oriented trips during COVID-19 (subsection 3.3.3.).

Only two peer-reviewed studies from the same city (Nanjing, China) have so far explored changes provoked by the pandemic on the socio-demographic and economic profile of BSS users, with both studies finding a reduction in the share of female as well as of younger users (Hua *et al.*, 2021; Wendong Chen *et al.*, 2022). Chen *et al.* (2022) argue that such declines can be attributed to, on the one hand, women being more likely to have to care for children (who due to the pandemic have shifted to online classes) and, on the other hand, younger cohorts being more likely to telework, leading in both cases to a higher decline in their travel needs. However, grey literature sources from New York City report an actual increase in the share of female users attributed to a safer cycling environment due to new segregated cycling lanes and a lower intensity of motorized traffic (Dwyer *et al.*, 2020; The New York Times, 2020b). As such, additional research is needed.

Crucially, bike sharing has provided essential workers with a transport alternative during COVID-19. BSS stations near healthcare facilities like hospitals have increased in popularity in cities such as London (H. Li *et al.*, 2021), Nanjing (Hua *et al.*, 2021) as well as Boston, New York City and San Francisco (City Monitor, 2020). Moreover, BSS stations located in neighbourhoods with higher levels of social disadvantaged groups (such as low-income households and minorities) were more resilient with lower ridership drops (Pase *et al.*, 2020; Hu *et al.*, 2021) and faster recovery rates (H. Li *et al.*, 2021; Hu *et al.*, 2021). Social disadvantaged groups, which constituted a significant share of essential workers during COVID-19 (e.g., food retail workers) (Tiako and Stokes, 2021), were more likely to commute even during lockdowns (Hu *et al.*, 2021; Tiako and Stokes, 2021) and, faced with restrictions (and infection fears) of using PT, turned to bike sharing as an affordable transport alternative.

3.3.6. ATTITUDES

The coronavirus pandemic has also changed the reasons for using bike sharing, with an increase in the importance of using BSS to avoid public transport and for social distancing (comouk, 2020; Teixeira, Silva and Moura e Sá, 2021b, 2022a). UK's 2020 cross-country survey of BSS users found that the main

reasons for (re)joining bike sharing for 23% of respondents were the lockdown and restrictions on PT (comouk, 2020). Teixeira, Silva and Moura e Sá (2021b), through conducting a travel survey to the users of *GIRA* (Lisbon's BSS), classified the reasons for using bike sharing into five motivational factors, ranking their importance before and during COVID-19. The authors uncovered that the motivations connected to COVID-19, specifically using *GIRA* to avoid PT and to social distancing, which the authors designated as the "social discomfort factor", had increased in importance being now only less important than the motivations connected to the system's coverage and quality (Teixeira, Silva and Moura e Sá, 2021b).

In fact, an emerging trend from the literature points to bike sharing being perceived as having a lower COVID-19 infection risk than other shared modes particularly PT, taxi and ride-hailing/sharing, but riskier than using personal modes such as private car, walking and personal bike (CUTR, 2020; Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour *et al.*, 2020; Bergantino, Intini and Tangari, 2021; Esposti, Mortara and Roberti, 2021; Teixeira, Silva and Moura e Sá, 2022a). For instance, through conducting a travel behaviour survey in Chicago, Shamshiripour *et al.* (2020) found shared bikes to have the fourth highest perceived infection risk, ranked after private cars, walking and personal bicycles but before PT, taxi and ride-hailing services. The perceived safety of BSS during COVID-19 is further supported by Teixeira, Silva and Moura e Sá (2022), whose survey aimed at Lisbon's *GIRA* users found that most of the respondents who quit or reduced *GIRA* usage during COVID-19 did so due to a decrease in their travel needs (particularly commuting) and not so much due to infection fears. Moreover, considering bike sharing as a safe mode to use during COVID-19 may induce an increase in BSS usage rates (Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Ceccato, Rossi and Gastaldi, 2021). Nikiforiadis, Ayfantopoulou and Stamelou (2020), which implemented a survey to the users of a small BSS in Thessaloniki (Greece) aimed at analysing their safety perceptions, found that respondents with a more positive view regarding the BSS safety during the pandemic were more likely to use bike sharing. Such findings underscore the need for operators to implement measures aimed at reducing the infection risk of using BSS, which will be amongst the topics addressed in the next section (specifically subsection 3.4.1.).

3.4. POLICY RESPONSES

BSS operators and public authorities have adopted several measures as a response to the coronavirus pandemic. In this section we provide an overview of the major policy responses that affected bike sharing, which were divided into four categories: COVID-19 infection risk reduction; system closure/expansion; discounted/free BSS trips; as well as service and business models. As in the previous section, we first summarize the main findings (Table 8), followed by a detailed description of each category.

Table 8 – Summary of the main BSS policy responses as a result of COVID-19 and their implications

Category	Main Findings	References
<i>COVID-19 infection risk reduction</i>	Several measures aimed at reducing COVID-19 infection risk were implemented on BSS, such as enhanced cleaning and disinfection protocols, enforcing social distancing as well as recommending users to disinfect their hands and wear a facemask Raising awareness about the implemented health and safety measures is important to increase trust on bike sharing, which in turn may boost BSS usage	(Freeman, 2020; K. Heineke, Kloss and Scurtu, 2020; NABSA, 2020; Seoul Metropolitan Government, 2020; Jobe and Griffin, 2021)
<i>System closure/expansion</i>	COVID-19 has led to the suspension/decrease of bike fleets and even closure of some systems, especially in the beginning of the pandemic. However, after the initial shock, BSS started to reopen, with some even expanding the number of stations and bikes BSS stations were deployed near hospitals to support healthcare workers	(Fischer, 2020; Freeman, 2020; NABSA, 2020; NYC DOT, 2020; World Economic Forum, 2020; Meddin Bike-sharing World Map, 2021; Teixeira, Silva and Moura e Sá, 2022a)
<i>Discounted/free BSS trips</i>	Several BSS operators implemented waivers/free trips especially for essential workers such as healthcare staff Equity concerns regarding the discounts as the majority of programmes excluded the most vulnerable essential workers (such as employees from food retail and services) who had the most to gain	(Fischer, 2020; NABSA, 2020; Pase <i>et al.</i> , 2020; Peters <i>et al.</i> , 2020; POLIS, 2020; Teixeira and Lopes, 2020; Combs and Pardo, 2021; TfL, 2021; Tiako and Stokes, 2021; Teixeira, Silva and Moura e Sá, 2022a)
<i>Service and business models</i>	To compensate from revenue losses, some BSS operators partnered with food-delivery companies while others implemented long-term rental services aimed at commuters	(COVID Mobility Works, 2020; Fischer, 2020; NABSA, 2020; Combs and Pardo, 2021)

3.4.1. COVID-19 INFECTION RISK REDUCTION

While shared bikes allow its users to maintain a social distance in most of their journey due to their single occupancy characteristics coupled with users riding in open spaces, BSS still possesses some infection risks particularly from contaminated surfaces and contact with other users when picking-up or dropping-off the bikes. Consequently, and following guidelines from public health authorities, BSS operators have implemented several measures aimed at reducing the infection risk of using a shared bike. These measures include (Freeman, 2020; NABSA, 2020; Seoul Metropolitan Government, 2020; Jobe and Griffin, 2021):

- Enhancing the cleaning and disinfection of shared bikes and other high touch surfaces such as touchpads at the stations, with some systems implementing anti-viral coatings on handlebars
- Providing hand sanitiser at BSS stations and introducing touchless options such as using *apps* and QR codes to unlock and lock bikes
- Ensure social distancing, namely by publicizing congestion data on BSS stations and even closing stations where overcrowding has been observed
- Recommending users to wear a facemask and to wash/disinfect their hands before and after using a shared bike

Concurrently, BSS operators should also publicize their efforts to reduce infection risks as better communicating the implemented infection prevention measures could increase the attractiveness of BSS during COVID-19, which in turn may lead to higher BSS usage rates. For instance, most respondents from a survey conducted by the consultant McKinsey & Company in seven countries mentioned frequent disinfection (47%), social distancing (43%) and user health checks (31%) as measures that would increase their likelihood of using shared micro-mobility (including BSS) (B. K. Heineke, Kloss and Scurtu, 2020). However, Jobe and Griffin (2021) found that of the eleven US cities they analysed, only five BSS operators had directly announced the sanitary and health measures taken to reduce the COVID-19 infection risk for their users. Moreover, a survey conducted by the authors to one of these systems (specifically San Antonio), revealed that only 57% of the users were aware of the actions taken by the operator to minimize the COVID-19 transmission risk (Jobe and Griffin, 2021).

3.4.2. SYSTEM CLOSURE/EXPANSION

Especially at the beginning of the coronavirus pandemic, several BSS suspended their services, with some operators decreasing their shared bike fleets and even permanently closing their systems. For example, the city of Austin (USA) ordered on March 2020 all shared mobility operators (including BSS) to reduce their fleets by 10% due to a reduction in demand (Fischer, 2020). The Meddin Bike-sharing World Map (2021) reported that 2020 was the first year since they started recording the number of BSS in operation (back in 2007) in which the number of BSS closing surpassed the number of systems launched (194 versus 115), with most closures occurring in the US (120 BSS closed).

However, after the initial shock, bike sharing systems started to reopen, with some even expanding the number of stations and bikes (Barbarossa, 2020), including opening new BSS stations near hospitals to improve access for healthcare workers (Freeman, 2020; NYC DOT, 2020). For example, Lisbon's *GIRA* was initially closed following the lockdown implementation, but reopened shortly after to support food-delivery couriers as well as healthcare staff (Teixeira, Silva and Moura e Sá, 2022a). The same Meddin Bike-sharing World Map (2021) report that by mid-2021 the number of new BSS was already superior to the number of systems closing. Furthermore, NABSA (2020) reports that the number of available shared bikes in North America had actually increase due to a surge in e-bikes which increased from 12,000 in 2019 to 23,000 in 2020 (while in comparison the number of shared e-scooters decreased 31%), with 75% of the suspended systems reopened by the end of the year. Similarly, China's largest dockless BSS operators announced in May 2020 the deployment of hundreds of thousands of shared e-bikes due to a boom in e-bike demand fuelled by an increase in the length of BSS trips (World Economic Forum, 2020).

3.4.3. DISCOUNTED/FREE BSS TRIPS

With the objective of providing a safe transport alternative during COVID-19, dozens of BSS across the world introduced discounted or free trips in the first months of the pandemic, particularly aimed at essential workers (Fischer, 2020; NABSA, 2020; Pase *et al.*, 2020; Peters *et al.*, 2020; Teixeira and Lopes, 2020; Combs and Pardo, 2021; Tiako and Stokes, 2021; Teixeira, Silva and Moura e Sá, 2022a), with some systems providing discounted or free trips for all users (Peters *et al.*, 2020; POLIS, 2020). For example, funded by the Scottish transport agency, Edinburgh and Glasgow provided free BSS trips on over 1,300 bikes during the summer of 2020 (POLIS, 2020), while in Flanders (Belgium) the government subsidized a 50% discount rate on BSS trips (Peters *et al.*, 2020). The Shifting Streets database, a collection of mobility measures implemented due to COVID-19 in almost 500 cities worldwide, found that the subsidization of BSS was the 5th most common response (out of 28 types of measures) with 73 known initiatives (Combs and Pardo, 2021).

Although there is still little evidence about the impact of such discount programmes on the overall BSS usage levels, these seem to have been well received with thousands of essential workers enrolling. For instance, more than 18,000 healthcare professionals joined the programme in London (TfL, 2021) while in New York the *Citi Bike* Critical Workforce programme, which in addition to healthcare staff also included PT employees, reached more than 33,000 workers (NYC, 2022). Assessing its effect in New York, Pase *et al.* (2020) found that the programme had a significant impact on *Citi Bike* ridership, with trips conducted by essential workers subscribing to the programme increasing from a residual share at its launch on March 2020 to representing 8.1% of all trips by June 2020. However, the fact that most of these discount programmes were limited to healthcare staff raises some equity issues as they excluded other types of essential workers, particularly low-income groups such as food retail workers which were amongst the groups most in need for alternatives to PT (Tiako and Stokes, 2021).

3.4.4. SERVICE AND BUSINESS MODELS

To minimize some of the pandemic negative impacts on their revenue streams, particularly during lockdowns, BSS private operators started to try additional service and business models. Some operators pivoted from providing short-term BSS trips to offering long-term monthly rentals and even directly selling bikes through test-driving models aimed at attracting former PT commuters to bike sharing (Fischer, 2020). Other systems have partnered with restaurants and similar delivery services, taking advantage of the heightened demand for home-delivery services such as take-out food (COVID Mobility Works, 2020; NABSA, 2020; Combs and Pardo, 2021). For example, in Syracuse (USA) the local BSS operator provided its entire 200 shared bikes fleet to restaurants for a daily fee (COVID Mobility Works, 2020). In their database, Shifting Streets report that such measures aimed at moving goods represented up to 2% of all mobility actions implemented globally (Combs and Pardo, 2021).

3.5. MAIN RESEARCH FINDINGS AND POLICY INSIGHTS

This review has synthesized the main impacts of the coronavirus on bike sharing (summarized in Table 7) as well as the subsequent policy responses adopted both by BSS operators and public authorities to minimize the pandemic's negative consequences (summarized in Table 8).

Amongst the most important findings, we uncovered robust evidence on the ability of BSS to act as a substitute mode to PT systems during the coronavirus as well as similar disruptive public health crises. Firstly, BSS have overall suffered lower ridership drops and faster recoveries than PT, with several bike sharing systems recovering and even surpassing pre-pandemic levels while PT ridership remains

battered. Secondly, the share of multimodal trips combining BSS and PT has declined, while at the same time the average trip duration of BSS trips has increased. Thirdly, bike sharing is considered to have a lower infection risk than PT, with users reporting to choose BSS during COVID-19 to avoid PT and to maintain a social distance during their trips. This has important policy implications: at a time when PT systems are still experiencing lower ridership levels and car usage is rising (with all the subsequent negative impacts), BSS can potentially provide an alternative. Nevertheless, further research is needed to better quantify the actual modal shift from PT to BSS registered during COVID-19. In here, replicating research designs applied in pre-pandemic modal shift studies (Campbell and Brakewood, 2017; Teixeira, Silva and Moura e Sá, 2021a) could offer a potential path.

This research has also found evidence on the importance of bike sharing as a leisure activity during coronavirus. With most options for exercising closed during the height of the pandemic, particularly indoor facilities such as gyms and swimming pools, BSS provided a means for exercising during COVID-19. Maintaining the recommended physical activity levels has important benefits not only regarding physical health (such as maintaining a healthy weight) but also on mental health (e.g., minimizing depression and anxiety) (WHO, 2020), both of which were negatively affected by the pandemic (Zachary *et al.*, 2020; Brodeur *et al.*, 2021).

Furthermore, bike sharing turned out to be a valuable transport alternative to essential workers and citizens who still had to travel during the height of the pandemic. BSS ridership near healthcare facilities and essential businesses (e.g., grocery stores) has increased, with record numbers of essential workers subscribing to bike sharing, taking advantage of the discount/free membership programmes provided by several operators. With PT heavily restricted during COVID-19, bike sharing was especially important to the most vulnerable groups, with BSS stations in deprived neighbourhoods increasing in importance. However, the restriction of the discount/free membership programmes to mostly healthcare staff excluded low-income essential workers such as those from food retail, depriving the affordability of BSS to some of the groups most in need of an alternative to PT during the pandemic. Bike sharing was already known to have equity issues prior to the pandemic, mostly due to these systems being concentrated in city centres where the density on both population and activities makes them more profitable (Teixeira, Silva and Moura e Sá, 2021a), leading operators to disregard more peripheral areas. In that sense, the waiver programmes implemented during the pandemic were a lost opportunity to minimize some of these inequity impacts as public funding to operators for subsidizing BSS trips in deprived neighbourhoods could have incentivized BSS to expand operations to less profitable areas.

This review opens several research paths. As already mentioned, it is paramount to further investigate the effects of COVID-19 on the modal shift dynamics, particularly between BSS and PT. It would be especially important to assess the ability of BSS to provide an alternative to PT to better inform policymakers considering, for instance, implementing or expanding BSS. Equally as important is to analyse the potential of BSS to ameliorate a surge in private car usage, particularly by avoiding a modal shift from PT users to the private car. In here, the deployment of shared e-bikes could be particularly useful as they increase the range of cycling trips. Even though preliminary evidence points to bike sharing being able to replace PT, most BSS in operation are too small-scale to effectively provide an alternative to most PT users. For instance, New York's *Citi Bike*, one of the largest BSS outside of China, broke its daily ridership record on September 11, 2021, with 135,005 rides (Citi Bike, 2021), which only corresponds to around 2.5% of the subway's pre-pandemic average ridership on a weekday (5.5 million trips) (Teixeira and Lopes, 2020). Expanding the systems, which continue to be overall limited to the city centres, could be a possible solution, which is supported by evidence from the largest BSS in the world all located in China. For example, the dockless bike sharing systems of Beijing have

more than 11 million users, which corresponds to half the city's population (21.5 million inhabitants), registering over 1.5 million trips per day (Chai *et al.*, 2021).

Qualitative studies, e.g., interviews or focus groups, are also needed as such research designs would allow a more in-depth understanding of potential individual behaviour changes regarding the use of bike sharing, namely on why users chose BSS as their mode of transport during the pandemic when other alternatives were available. Surveys aimed at gauging the attitudes of the broad population (i.e., non-users) towards BSS during COVID-19 would also be useful to estimate the potential for bike sharing usage at the city level. Additional studies are required aimed at exploring the impact of the pandemic on the socioeconomic and demographic profile of BSS users. For instance, COVID-19 could have impacted the BSS gender unbalanced verified in countries with low cycling shares, such as the USA and UK, in which women are much less likely to use bike sharing (as well as cycling) (Ricci, 2015; Teixeira, Silva and Moura e Sá, 2021a), being attributed to women having higher safety concerns (Pucher and Buehler, 2008; Wang and Akar, 2019). However, as a response to the pandemic, public authorities across the world have implemented several measures aimed at increasing cycling safety such as car-free streets and segregated cycling lanes (ECF, 2020), which in turn could have made BSS (and cycling) more attractive to women.

As the coronavirus pandemic continues to disrupt the world, its potential long-term negative effects on transport, such as a permanent PT ridership loss, increase. Concurrently, the window of opportunity for avoiding climate disruption is closing fast, with the latest IPCC report grimly estimating that policymakers have only a few years left to avoid some of the worst negative climate outcomes (IPCC, 2022). However, the same report also cites that promoting sustainable modes of transport is amongst the most cost-effective measures to rapidly decrease CO₂ emissions (IPCC, 2022). Yet, due to rising fuel prices, governments across the world are further subsidizing car fuel costs (euronews, 2022), regardless of the impacts that such measures will have in preventing climate breakdown. Thus, and bearing in mind the findings of the present study, we propose an alternative strategy in which governments consider BSS (as well as other types of micro-mobility such as e-scooter sharing) as new forms of PT, properly funded and integrated with the broad transport system. Such approach could potentially provide citizens with a resilient transport alternative that does not jeopardize current decarbonization targets.

4.

THE ROLE OF BIKE SHARING DURING THE CORONAVIRUS PANDEMIC: AN ANALYSIS OF THE MOBILITY PATTERNS AND PERCEPTIONS OF LISBON'S GIRA USERS

This chapter presents an integral reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (2022) ‘The role of bike sharing during the coronavirus pandemic: an analysis of the mobility patterns and perceptions of Lisbon’s GIRA users’, Transportation Research Part A: Policy and Practice. Elsevier. 159, pp. 17–34. doi: 10.1016/j.tra.2022.03.018.”

ABSTRACT

COVID-19 has dramatically impacted urban mobility, of which public transport (PT) has been particularly affected. With PT ridership plummeting due to infection fears and many people returning to work, there is a danger of a steep rise in car use that would exacerbate environmental and health problems. Therefore, other modes such as bike sharing should be considered as potential alternatives during the coronavirus pandemic.

This study focuses on assessing how coronavirus has impacted bike sharing by implementing a travel behaviour survey to the users of *GIRA*, the bike sharing system (BSS) of Lisbon. While the coronavirus has led some to decrease the frequency of use or quit the system, other users have increased the usage or joined *GIRA* during the pandemic. Furthermore, most users who have quit or decreased the usage of *GIRA* justify their decision not so much on avoiding the risk of infection (although for some it is an important reason) but on having stopped commuting due to COVID-19. The survey has also revealed substantial changes not only on the usage patterns of *GIRA* users but also on their relationship with other modes of transport. While before the pandemic, most respondents were shifting from PT to *GIRA*, that percentage has declined, with an increase on the share of users replacing walking, private car, and personal cycling. Moreover, the motivations for using bike sharing related with avoiding PT and maintaining a social distance during the trip have gained more relevance. Concurrently, the perceived safety of using PT has drastically declined, and while the perceived safety of using *GIRA* has also decreased it was in a much smaller scale.

Policy insights can be derived from this research on how bike sharing can contribute to a more sustainable and resilient urban transport system. During infectious public health crises such as COVID-19, BSS can be a viable transport alternative, not only providing the population with an affordable mode of transport where social distancing can be maintained in most of the trip but also mitigating a modal shift from PT to the private car.

Keywords: COVID-19; Bike sharing systems; Modal shift dynamics; Public Transport; Car use; Safety perceptions

4.1. INTRODUCTION

The coronavirus pandemic has caused catastrophic impacts on society, provoking one of the worst health and economic crisis in modern history. The large-scale lockdowns implemented all over the world have led to “the Great Pause” (Wolfe, 2020), where entire economies simply stopped overnight in order to “flatten the curve”, lowering the rate of infection and providing precious time to the healthcare systems to avoid being overrun by COVID-19.

Perhaps, no better example illustrates such tectonic shocks in our society as the transport sector. With several countries implementing restrictions to the movement of people, limiting mobility to essential trips and strongly promoting or even mandating teleworking whenever deemed feasible, our usually congested transport networks were emptied during lockdown. Lower traffic volumes and a lack of available options for exercising as a result of the closure of most non-essential services (which included exercising facilities such as gyms, swimming pools and even public parks) have led to a new push and acceptability of walking and cycling (Budd and Ison, 2020). Such shift to walking and cycling could not only contribute to a more sustainable mobility but also have positive impacts on the subjective well-being of the population (De Vos, 2020). Furthermore, the lockdown measures had also unexpected positive environmental impacts, including substantial air quality improvements and reductions in noise pollution (Zambrano-Monserrate, Ruano and Sanchez-Alcalde, 2020), as well as leading to the largest recorded decrease in global CO₂ emissions (Liu *et al.*, 2020), offering glimpses of a possible more sustainable world after coronavirus.

However, as countries gradually reopen, traffic levels are slowly returning to pre-pandemic levels (INRIX, 2020) and with COVID-19 still a threat, we are in danger of witnessing a modal shift from public transport (PT) to private car due to infection fears (de Haas, Faber and Hamersma, 2020; Shamshiripour *et al.*, 2020). A surge in car use would undeniably lead to several negative outcomes such as exacerbating climate change (Liu *et al.*, 2020), a likely even bigger threat than the present coronavirus pandemic (Lenton *et al.*, 2019). Thus, and considering that public transport ridership can be expected to continue to be negatively affected by COVID-19 in the foreseeable future (De Vos, 2020), alternative modes of transport such as cycling should be considered.

In the present study we focus on one of the most popular policies promoting cycling – bike sharing. Bike sharing systems (BSS) are characterized by the provision of bicycles typically distributed across a network of stations (docked BSS) or predefined operational areas (*dockless* BSS) that can be rented for a short-term period (Demaio, 2009; Fishman, 2016). BSS have seen a remarkable rise in the last decade with more than 2000 systems currently in operation mostly in China, Europe and North America (DeMaio and Meddin, 2020).

The objectives of this research were twofold. Firstly, we aimed at evaluating how COVID-19 has affected the mobility patterns of BSS users (including modal shift dynamics, their frequency and purpose for using BSS). Secondly, we investigated if COVID-19 has changed the perceptions and motivations for using bike sharing, especially those related to safety, health concerns and accessing or avoiding PT. To accomplish this, we implemented a travel behaviour survey to the users of Lisbon's BSS entitled *GIRA*. Ultimately, our goal is not only to understand how bike sharing has performed during the coronavirus pandemic, but also what is its potential role within the broad transport system, particularly regarding its ability in avoiding a modal shift from PT to the private car.

The remainder of the paper is structured as follows. Next, we present an overview of the COVID-19 main impacts on urban mobility as well as the potential role of cycling and bike sharing in ameliorating such effects (Section 4.2.). This is followed by a brief presentation of the case-study, the research approach as well as the design and implementation of the survey (Section 4.3.). The results are then

presented (Section 4.4.), followed by their discussion (Section 4.5.). Finally, the paper ends with the policy implications of our findings within the perspective of planning for a more sustainable transport system (Section 4.6.).

4.2. COVID-19 AND URBAN MOBILITY

Virtually in all affected regions a severe decrease in mobility has been observed as a result of the partial or total lockdowns implemented by governments in an effort to slowdown the spread of COVID-19 (Hadjidemetriou *et al.*, 2020; Sharifi and Khavarian-Garmsir, 2020). For instance, in the Netherlands, de Haas, Faber and Hamersma (2020) observed the number of trips and distance travelled to drop, respectively, 55% and 68% comparing with the fall of 2019, while in the UK, Hadjidemetriou *et al.* (2020) found a 60%, 80% and 60% decline in daily trips from, respectively, car, PT and walking.

PT networks are amongst the most affected modes with ridership levels plummeting to historic lows. For example, the New York City's subway suffered a 90% ridership drop during the lockdown period (March 20th to June 8th, 2020) comparatively to the same period in 2019, with the ridership levels in September 2020 still just 30% of pre-pandemic levels (MTA, 2021). Likewise, Bucsky (2020) observed a 80% percentual drop in PT trips compared to an overall mobility reduction of 57%. The same trend was also observed in Santander (Spain) with a 93% reduction in PT usage comparatively to an overall mobility decline of 76%, with a less pronounced drop of 68% in car usage (Aloi *et al.*, 2020). The exceptionally severe impact of coronavirus on PT networks can be attributed to infection fears due to the risk of coronavirus transmission in enclosed, and often overcrowded, vehicles. Indeed, several governments have recommended their citizens to avoid using public transport in favour of private modes of transport, including the car (GOV.UK, 2020), although emerging evidence seems to point to a lower transmission risk of PT than previously feared (Hu *et al.*, 2020; The New York Times, 2020a). Such public aversion to PT use during the coronavirus pandemic is evident in recently conducted travel behaviour surveys (de Haas, Faber and Hamersma, 2020; Shamshiripour *et al.*, 2020). de Haas, Faber and Hamersma (2020), through a longitudinal survey of a representative sample of 2500 respondents in the Netherlands, assessed daily behaviour and attitudes before and during the coronavirus pandemic. The authors found less than 10% of the respondents to now have a positive attitude towards PT while the attitudes towards the car had improved (de Haas, Faber and Hamersma, 2020). Similarly, a survey of 915 residents from the Chicago metropolitan area found 93% of the respondents to perceive a medium to extreme risk of exposure to the coronavirus associated to PT (Shamshiripour *et al.*, 2020). In contrast, only 14% of the respondents had such a risk perception towards using a private car, while 23% and 29% considered, respectively, walking and using personal bicycles a risk (Shamshiripour *et al.*, 2020).

With public transport ridership expected to remain below pre-pandemic levels as long as COVID-19 remains a threat, there is a risk of a modal shift from PT to private cars which would entail severe repercussions from a sustainability standpoint (Douglas *et al.*, 2011; Graham-Rowe *et al.*, 2011). Such increase in car use could even worsen the present coronavirus pandemic as evidence has been found on higher levels of air pollution increasing transmission and mortality rates of COVID-19 (Pozzer *et al.*, 2020; Sharifi and Khavarian-Garmsir, 2020; Wu *et al.*, 2020).

A possible path to ameliorate such undesirable modal shift is to consider alternative modes of transport, especially walking and cycling. Walking and cycling have already been gaining relevance as a sustainable and healthy alternative to public transport and car use during the coronavirus pandemic (De Vos, 2020), with several cities allocating vast swaths of street space to these modes. For instance, according to the European Cyclists Federation more than 2,000 km of new dedicated walking and cycling infrastructure has been announced by several European cities, with more than 1,000 km already

implemented including widening of sidewalks, expansions of cycling networks, implementation of traffic calming measures and car-free zones (ECF, 2020). Such strategies are supported by de Haas, Faber and Hamersma (2020), which observed walking and cycling to be the least affected modes during the pandemic, with the share of walking trips sharply increasing. Furthermore, while the overall average trip distance had decrease in most modes, an increase was observed in the case of cycling and walking trips (de Haas, Faber and Hamersma, 2020).

Cycling can be a particularly viable alternative to car travel in urban areas, being competitive or even faster than driving in distances up to 5 km (J. Dekoster, 1999; Ellison and Greaves, 2011), with e-bikes capable of doubling that range (Annick Roetynck, 2010). Likewise, bike sharing was found to have competitive travel times comparatively to cars in Lyon (Jensen *et al.*, 2010) and to taxis in New York City (Faghih-Imani *et al.*, 2017), with former car users mentioning shorter travel times among the reasons for shifting to BSS (Yang *et al.*, 2016). A recent comprehensive review of the main impacts of bike sharing has reported BSS to be particularly suitable for complementing PT, either by expanding PT catchment areas or by providing an alternative to overcrowded services, and to be able to replace car trips, presenting several potential advantages that could be enhanced to further promote car reductions (Teixeira, Silva and Moura e Sá, 2021a). Furthermore, BSS have already been shown to increase the resilience of the transport network to disruptive events prior to the coronavirus pandemic as illustrated by Saberi *et al.* (2018). Analysing the impact of a subway strike on London's BSS, Saberi *et al.* (2018) observed that during the subway strike both the number and duration of BSS trips had increased (85% and 88%, respectively). In fact, Teixeira and Lopes (2020) have already found evidence suggesting BSS to be playing a similar role during the current coronavirus pandemic. Assessing how the BSS and subway of New York City responded during the COVID-19 lockdown in March 2020, the authors noticed that the BSS ridership drop was lower than of the subway (71% versus 90%), with the average duration of BSS trips increasing from 13 min to 19 min (Teixeira and Lopes, 2020). Moreover, Teixeira and Lopes (2020) uncovered evidence of a possible modal shift from some subway users to the BSS. Such findings are supported by Bucsky (2020), who observed bike sharing to suffer the lowest ridership decrease (2% versus an overall 57% mobility decrease, with personal cycling decreasing 23%) in Budapest. Furthermore, shared bikes had a lower perceived risk comparatively to PT or other shared modes (taxi and ride-hailing) in the Chicago travel survey, albeit the risk perception was significantly higher comparatively to personal modes (Shamshiripour *et al.*, 2020).

4.3. DATA AND METHODS

4.3.1. CASE-STUDY

4.3.1.1. URBAN MOBILITY IN LISBON BEFORE COVID-19

Lisbon is the most populous municipality and the capital of Portugal. According to the Portuguese National Institute of Statistics (INE, 2018), Lisbon has a population of 504,964 inhabitants with a population density of 5,047.1 inhabitants/km². Regarding its modal share, a travel survey conducted in 2017 revealed the municipality to be predominantly car-focused with almost half the trips made by private motor vehicles (46.1%), followed by walking (29.8%), public transport (21.1%) and a residual use of cycling (0.6%) (INE, 2018).

To tackle this overreliance on car use, in the last few years Lisbon has started to implement several measures, including promoting cycling as a mode of transport. Measures such as the construction of dedicated cycling infrastructure (Câmara Municipal de Lisboa, 2019a) and the implementation of 30 km/h zones (Câmara Municipal de Lisboa, 2019b) across the municipality are examples of this policy shift. To further promote cycling, the municipality has decided to implement a public-owned BSS

entitled *GIRA* at the end of 2017. Lisbon's *GIRA* is a docked BSS and currently has 700 shared bikes, comprised both by conventional and electric-assisted bikes, distributed across 83 stations located mostly in the city centre (Figure 15).

Indeed, bike counts conducted before the coronavirus pandemic in the city centre suggest that such measures are being effective. Between 2016 and 2017 bike counts registered a 3.5-fold increase in the number of cyclists and an additional 2.5-fold growth between 2017 and 2018 after the implementation of bike sharing, with 34% of all observed cycling trips in 2018 being conducted by *GIRA* users (Félix, Cambra and Moura, 2020).

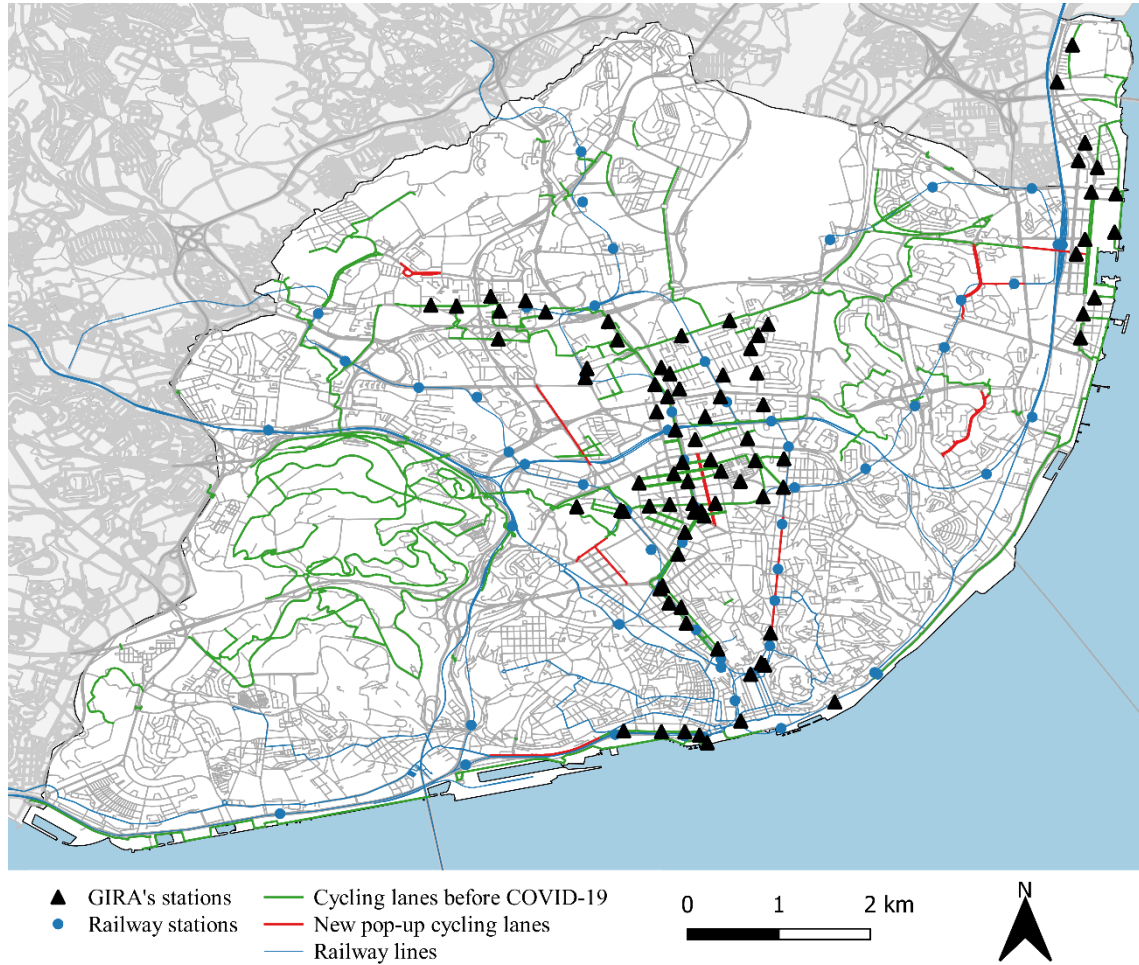


Figure 15 – Location of *GIRA* stations in Lisbon

4.3.1.2. COVID-19 AND LISBON'S POLICY RESPONSES

As in several other European countries, Portugal registered two COVID-19 waves in reported cases throughout 2020 (Figure 16), with the first wave occurring during the spring and the second one at the beginning of autumn. The first two cases of COVID-19 in Portugal were confirmed on March 2nd, 2020, and by March 18th, the State of Emergency was declared, leading to the full lockdown of the country that lasted until May 3rd. During the summer, the pandemic seemed under control leading to a gradual reopening of the country. However, the number of COVID-19 cases started again to rapidly increase at the beginning of autumn, marking the start of a more devastating second wave which forced the country, on November 9th, to reinstate the State of Emergency and with-it new restrictions on mobility (which would culminate in a new full lockdown at the beginning of 2021).

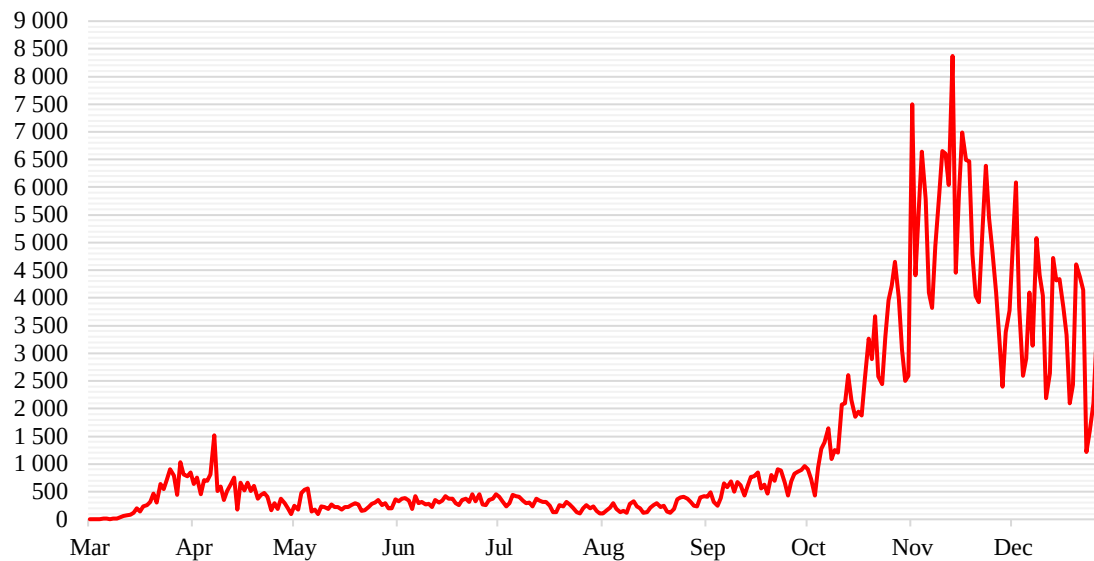


Figure 16 – Variation in the number of COVID-19 new daily cases in Portugal throughout 2020

Google's mobility reports from March to December provide a clear picture of the coronavirus impacts in Lisbon (Figure 17), revealing a substantial decrease on trips related to commuting, shopping and leisure, as well as a sharp decline in PT ridership.

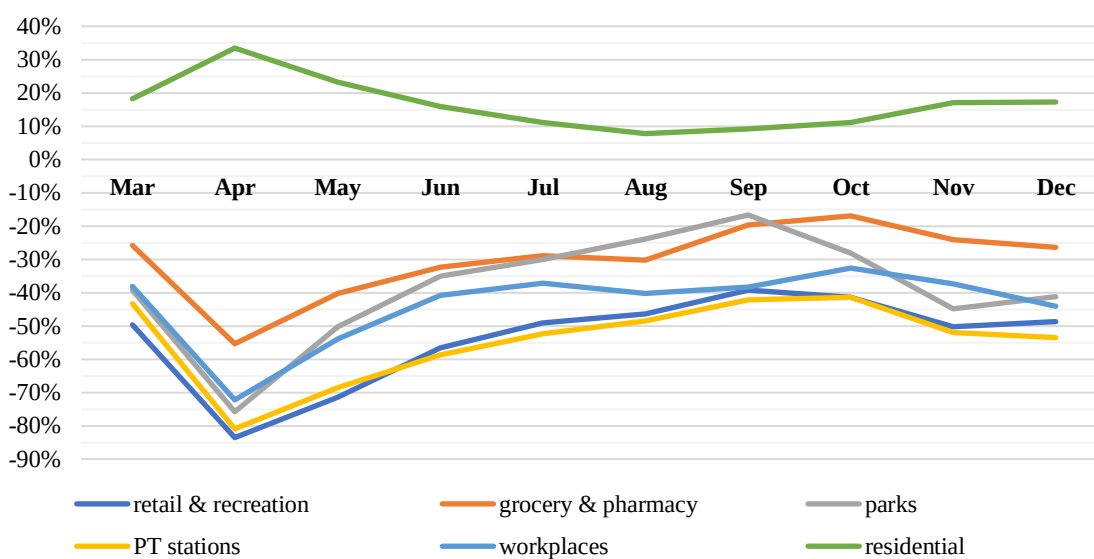


Figure 17 – Monthly percentual changes of Lisbon's mobility trends between March and December, 2020, comparatively to a 5-week median baseline between January 3 and February 6, 2020, to several activities (Google, 2020)

As a response to the plummeting of PT use and to avoid a surge in car use, Lisbon unveiled in May 2020 a comprehensive package for promoting walking and cycling in the city. Such package included the construction of 76.5 km of pop-up dedicated cycling lanes, the expansion of safe bicycle parking and the establishment of a 3 million euro fund for subsidizing citizens in buying and repairing bicycles (Câmara Municipal de Lisboa, 2020a). Figure 15 shows in red the already implemented new pop-up cycling lanes.

4.3.1.3. GIRA USAGE DURING COVID-19

Regarding *GIRA*, in an initial phase the BSS was closed with the announcement of the State of Emergency on March 18th (EMEL, 2020c). However, the system was reopened shortly after, first with the aim of supporting food-delivery couriers and later to provide a safe mode of transport for essential workers with healthcare workers, security forces and civil protection agents receiving free trips for two months (Lisbon City Council, 2020). The BSS continued to operate normally throughout 2020 with enhanced cleaning protocols in accordance with the guidelines from the Portuguese Directorate-General of Health.

The COVID-19 impact on *GIRA* monthly ridership and number of active users is presented, respectively, in Figure 18 and Figure 19. Both the number of trips and of active users have drastically decreased during the first lockdown, particularly in April. However, with the end of the lockdown the system starts to rebound, with its summer levels even surpassing those of 2019, particularly regarding ridership. With the beginning of the second COVID-19 wave in the fall, ridership and user levels start again to rapidly decrease but at a lower rate comparatively to the first wave.

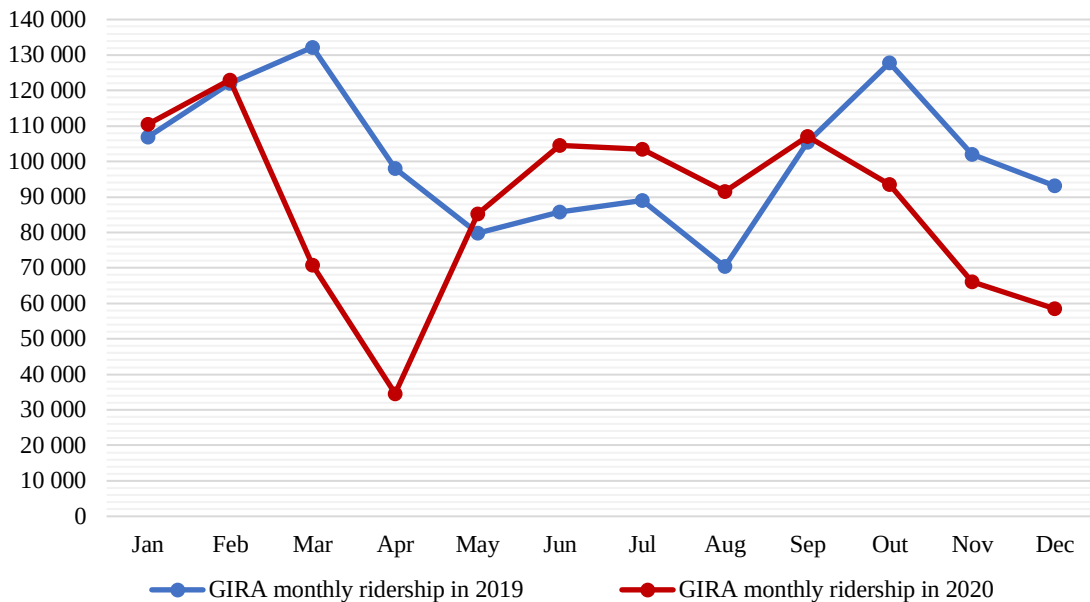


Figure 18 – *GIRA* monthly ridership in 2019 and 2020

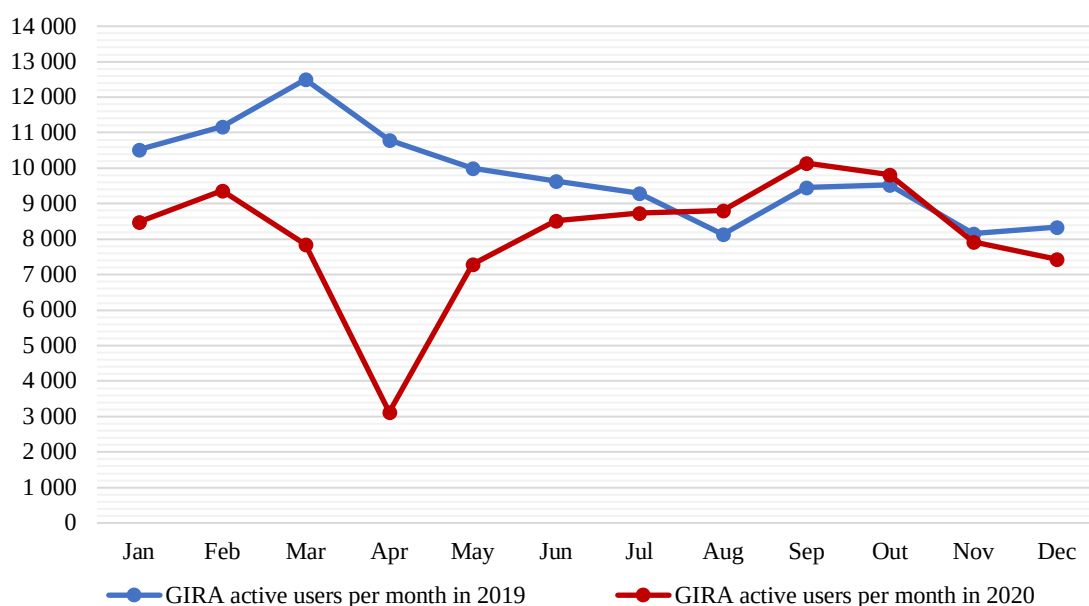


Figure 19 – GIRA monthly number of active users in 2019 and 2020

4.3.2. RESEARCH APPROACH AND SURVEY DESIGN

An online travel behaviour survey was designed aimed at evaluating how COVID-19 has changed the travel behaviour, as well as preferences and motivations related to safety, health and the relationship with PT of BSS users. In this study we will focus on three groups of *GIRA* users, classified according to the impacts of COVID-19 on their relationship with the system:

- *Being a GIRA user before the COVID-19 pandemic and continuing to currently use it*
- *Have joined GIRA during the COVID-19 pandemic*
- *Being a GIRA user, but having stopped using the system as a result of the COVID-19 pandemic*

To assess the impact of COVID-19 on the users' behaviour we started the survey with an introductory note explaining that the questionnaire would have an evaluation component of the COVID-19 effects on *GIRA* usage patterns. Next, respondents were informed that, in certain questions, they would be asked to compare their current daily routines (fully within the COVID-19 pandemic) with those before the pandemic (respondents were asked to refer to the first two months of 2020). We considered the answers of the users who have stopped using *GIRA* as a result of the COVID-19 pandemic as relevant for analysis of the pre-pandemic period, while the answers of the new users (who have joined the system during the pandemic) as relevant for the pandemic period. Furthermore, for the respondents who were users before the pandemic and continue to currently use *GIRA*, we have employed additional retrospective questions, asking them to compare their travel behaviour before and during COVID-19. With this categorization we were able to compare the behaviour of *GIRA* users before and during the pandemic.

Three main groups of questions were considered, all of which with closed-ended responses. The first group aimed at assessing the travel behaviour of respondents, including their main mode of transport, frequency of BSS use, trip purpose, modal shift dynamics (which mode would they use if the BSS was not available) and the multimodal nature of BSS trips (e.g., if BSS is being combined with other modes).

The second group of questions focused on the motivations for using BSS that could have been affected by the coronavirus pandemic, asking respondents to classify the importance of each motivation in their decision to use *GIRA* through a 5-point Likert scale. Specifically, we hypothesized that the importance

of motivations related to accessing or avoiding PT could have changed as people may try to avoid public transport due to infection fears. Likewise, motivations related to health concerns and for maintaining a social distance may have gained relevance. Additionally, as people might now avoid some of their previous options for exercising, particularly indoor facilities, by perceiving a higher risk of infection, we also included the motivation of fitness improvements. Finally, as the pandemic, on the one hand has led to a decrease in traffic volumes and, on the other hand, the municipality of Lisbon has implemented new dedicated cycling lanes, we have also assessed the motivations of low car traffic speeds in the trip's route and the existence of cycling lanes serving the trip.

Lastly, we requested all respondents to assess, through a 5-point Likert scale, how safe they felt (perceived safety) using several modes of transport (including *GIRA*) in Lisbon before COVID-19 and in the current situation (the survey question is provided in Appendix A3). The concept of safety goes beyond the perceived risk of infection due to the coronavirus. For example, regarding using cycling or bike sharing, one of the main barriers is the perceived danger of cycling alongside motor vehicles (Heinen, van Wee and Maat, 2010; Fishman, Washington and Haworth, 2012; Teixeira, Silva and Moura e Sá, 2021a). As the coronavirus has led to a decline in traffic and the Lisbon municipality has implemented new dedicated cycling infrastructure, the respondents could now perceive a safer environment for cycling (despite the risk of infection).

4.3.3. SURVEY IMPLEMENTATION AND ANALYSIS OF RESULTS

We followed an opportunistic sample approach, disseminating the survey through social media and the local press. The dissemination included publicizing the survey through faculties mailing lists, official pages of parish councils as well as pages and groups containing residents living or working in areas with BSS stations. Furthermore, the survey was widely publicized in cycling and bike sharing associations of Lisbon. The survey was available online for approximately one month between the end of September and throughout October, 2020, obtaining a sample of 215 valid answers.

Descriptive statistics as well as the non-parametric Wilcoxon Signed Rank and Mann-Whitney U tests were then applied to the survey's results to compare and to assess possible significant differences in the behaviour of BSS users before COVID-19 and in the current situation. Wilcoxon Signed Rank and Mann-Whitney U tests are the non-parametric equivalents of the paired and independent t-tests, respectively, and are used when the dependent variable is ordinal (Field, 2013d). Wilcoxon Signed Rank test is employed when the same subjects are evaluated under two different scenarios, while Mann-Whitney U test is designed to detect differences between two independent groups. In this study, we have used Wilcoxon Signed Rank tests to compare the answers of the same respondents before the coronavirus pandemic and in the current situation, while employing Mann-Whitney U tests to compare the answers of different groups of respondents.

4.3.4. SAMPLE

Table 9 summarizes the composition of our sample, presenting standard socioeconomic and demographic characteristics of the respondents. To assess the representativeness of our sample we compared it with a larger survey conducted by *GIRA*'s operator between January and February 2019 (Moura and Félix, 2019). We also compared the socio-demographic characteristics of *GIRA* users with the 2017 Household Travel Survey of Lisbon (INE, 2018). As the questions are from different surveys, some matching was necessary to make them comparable.

Most of our respondents live in the city of Lisbon, with a predominance of male users (58%). Furthermore, the majority of respondents have a higher education degree (85%) and are employed

(72%). Regarding mobility options, most respondents report to have a driving's license (87%), as well as access to a car (78%) and a bike (56%), however the majority does not have a public transport monthly subscription (56%).

In general, our sample is similar to the 2019 operator's survey, although it has a higher percentage of women as well as of users residing in the city of Lisbon. It also presents a lower percentage of respondents working. This can be explained by differences in the questionnaires' designs (the 2019 survey included working students in the working category, whereas in our survey working students were grouped in the studying category) and by the COVID-19 impact on employment. Comparatively to the general population of Lisbon, *GIRA* users (in both the 2020 and 2019 surveys) tend to be male, employed, younger and to have a higher education degree, which is in line with previous research characterizing the average BSS user (Ricci, 2015). Additionally, *GIRA* users also have greater access to personal bicycles.

Regarding the three groups of *GIRA* users, the respondents who were already users of *GIRA* before the pandemic and continue to currently use constitute the largest group (154 valid answers), followed by the new *GIRA* users who joined during the COVID-19 pandemic (32 valid answers) and the former *GIRA* users who no longer use the system due to the pandemic (29 valid answers).

Table 9 – Comparison of the socioeconomic and demographic characteristics of *GIRA* users, from the 2020 survey (N=215) and from the 2019 survey (N=4,970), with the general population of the City of Lisbon (N= 12,890)

		2020 <i>GIRA</i> Survey		2019 <i>GIRA</i> Operator's Survey	2017 Lisbon Household Travel Survey
		n	%	%	%
Place of residence	Lisbon City	193	90%	71%	100%
	Lisbon Metropolitan Area	22	10%	29%	0%
Gender	Female	90	42%	33%	47%
	Male	125	58%	67%	53%
Age	≤ 24	38	18%	15%	21%
	25-44	114	53%	60%	26%
	45-64	62	29%	24%	30%
	> 64	1	0%	1%	24%
Education	Basic Education	1	0%	2%	29%
	Secondary Education	31	14%	15%	18%
	Higher Education	183	85%	83%	53%
Employment status	Working	154	72% ^a	84% ^b	55%
	Not working	10	5%	2%	6%
	Other (of which are students)	51 (49)	23% (96%)	13% (88%)	40% (N/A)
Driving's license	No	28	13%	N/A	33%
	Yes	187	87%		67%
PT monthly pass	No	120	56%	61%	64%
	Yes	95	44%	39%	32%
Car availability	No	48	22%	16%	24%
	Yes	167	78%	84%	76%
Bicycle availability	No	94	44%	49%	78%
	Yes	121	56%	51%	22%

^a Does not include working students. ^b Includes working students.

4.4. THE EFFECTS OF COVID-19 ON GIRA USERS

We will focus our analysis in two main themes. First, we will examine the main changes in the usage patterns and travel behaviour of *GIRA* users (subsection 4.4.1.). Then, we will look at possible changes in the respondents' motivations and perceptions related to safety, health concerns and with accessing or avoiding PT that could help to explain the observed mobility changes (subsection 4.4.2.).

4.4.1. TRAVEL BEHAVIOUR

4.4.1.1. GIRA USAGE

We started by analysing the change in the usage patterns of our subgroups of *GIRA* users due to the coronavirus pandemic (Figure 20). The pandemic has led to very different responses within *GIRA* users. While 35% of the respondents have decrease or stopped using *GIRA* as a consequence of the pandemic, 30% have increase their usage or have joined *GIRA* during COVID-19. The usage patterns of the remaining 35% seem to not be particularly affected by the pandemic.

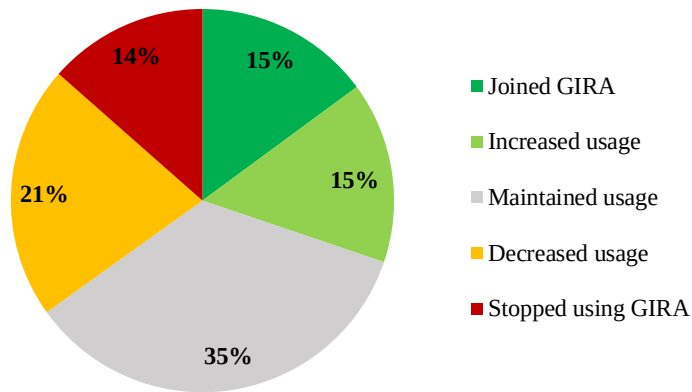


Figure 20 – Classification of *GIRA* users according to their changes in usage as a consequence of COVID-19

We asked the respondents to justify their changes in the usage patterns of *GIRA* during the coronavirus pandemic. For the users who have joined *GIRA* during the pandemic, 68.8% have indicated that their reason for joining was the consequences of COVID-19. Regarding the users who have stopped or decrease their usage, their reasons for doing so are represented in Table 10.

Table 10 – Main reasons for decreasing or quitting using *GIRA* as a consequence of COVID-19

	Decreasing usage (N=46)	Quitting (N=29)
The trip purpose no longer exists	62.0%	53.4%
To avoid the risk of infection	9.8%	36.2%
Other reasons	28.3%	10.3%

Most of the users who have decrease or stopped using *GIRA* during the coronavirus justify such decision on the fact that their main trip purpose for using *GIRA* no longer exists, with only a small share avoiding using *GIRA* due to the risk of infection (although infections fears are more substantial among the users who quitted the system).

We also asked respondents to select their typical usage frequency of *GIRA*. In here, we have compared the frequency of use before COVID-19 and in the current situation (considering all users), as well as the specific frequency of use of our three subgroups (users before and during

COVID-19, respondents who stopped using *GIRA* due to COVID-19 and new users who joined during the pandemic), with the results presented in Figure 21.

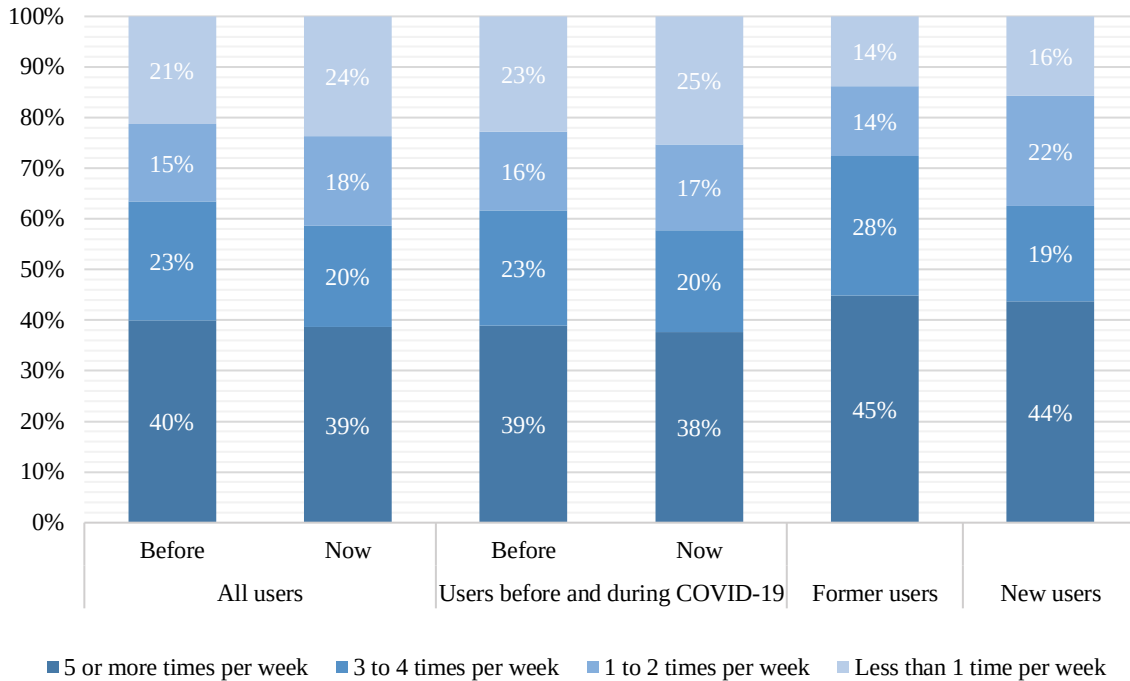


Figure 21 – Comparison of *GIRA* usage frequency before COVID-19 and in the current situation considering all users (N=215), users before and during COVID-19 (N=154), respondents who stopped using *GIRA* due to COVID-19 (N=29) and new users who joined during the pandemic (N=32)

We can assert that most of our respondents are frequent users, meaning users who make 3 or more trips per week, both before the coronavirus pandemic and currently. Remarkably, contrary to what we had expected, which would be a reduction in usage frequency in line with the overall decrease in mobility registered in Lisbon (Figure 17) and elsewhere, the frequency of use remained stable, with only a slight decline in the overall percentage of frequent users.

4.4.1.2. PURPOSE OF *GIRA* TRIPS

The purposes of the trips conducted with *GIRA* may have also been affected by COVID-19. In Figure 22 we present the variation on the trip purposes of *GIRA* before the pandemic and in the current situation.

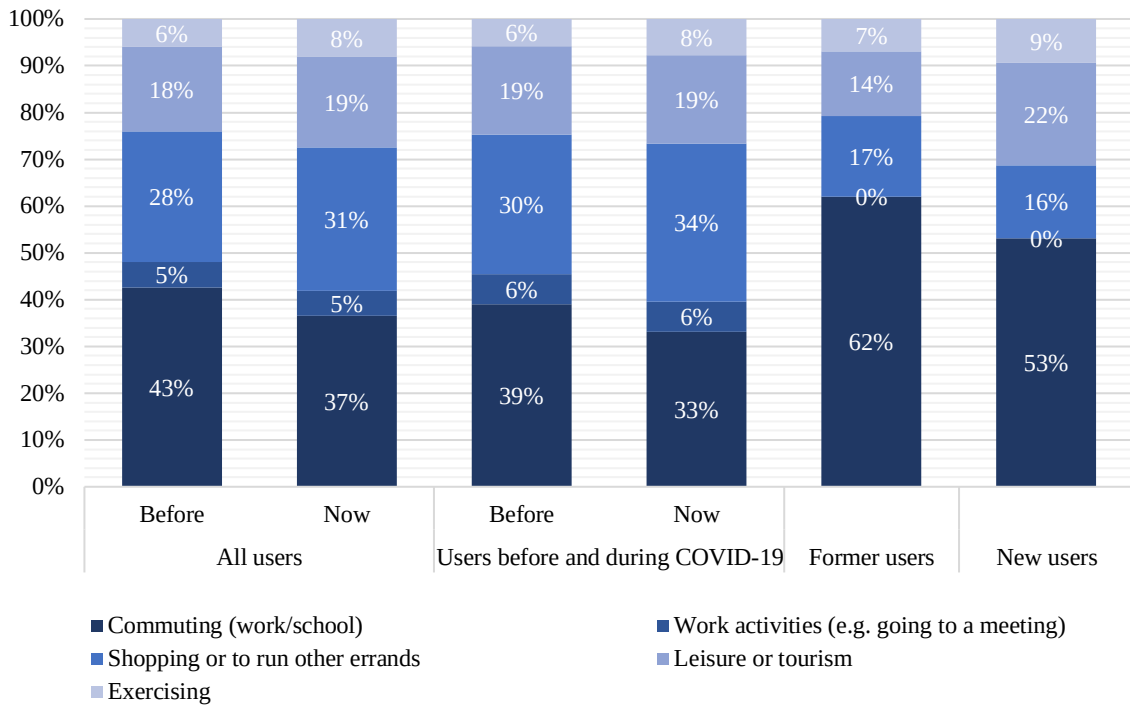


Figure 22 – Comparison of *GIRA*'s trip purposes before COVID-19 and in the current situation considering all users (N=215), users before and during COVID-19 (N=154), respondents who stopped using *GIRA* due to COVID-19 (N=29) and new users who joined during the pandemic (N=32)

Comparing both periods, we observe a decline in the share of *GIRA* trips having as purpose commuting, with such decrease replicated in the subgroups. Furthermore, for most of the respondents who stopped using *GIRA* due to COVID-19 their main trip purpose was commuting. These results seem to be related to the increase of the share of people no longer commuting as a consequence of the coronavirus pandemic. Interestingly, most of the new users who joined during the COVID-19 pandemic also indicate commuting as their main trip purpose, which may indicate that some people are considering *GIRA* as an alternative to other modes of transport such as public transport.

4.4.1.3. MAIN MODE OF TRANSPORT BEFORE AND DURING COVID-19

Next, we analysed the main mode of transport used in commuting trips (i.e., trips from home to work or school) of the respondents before the coronavirus pandemic and in the current situation. Respondents could select a single mode or multiple modes, with walking trips being considered only if they were exclusive or represented more than 5 consecutive minutes in a combined trip. In addition, respondents could select the option of no longer commute in the current situation, with 18% (39 respondents) selecting that option.

Figure 23 presents the modal share of the most frequently chosen modes of transport before the pandemic and in the current situation. The figure reveals a severe decrease in the modal share of public transport, while the share of most the other modes has increase. Indeed, whereas before the pandemic PT was the most chosen mode (36.4%), followed by bike sharing (22.2%) and walking (19.5%), currently PT has been surpassed both by bike sharing and walking with a modal share of 21.9% comparatively to 27.3% and 23.3%, respectively. In fact, *GIRA* is now the most chosen mode. More worrisome from a sustainability point of view, the modal share of private car has increase from 10.8% before the pandemic to 14.7% nowadays.

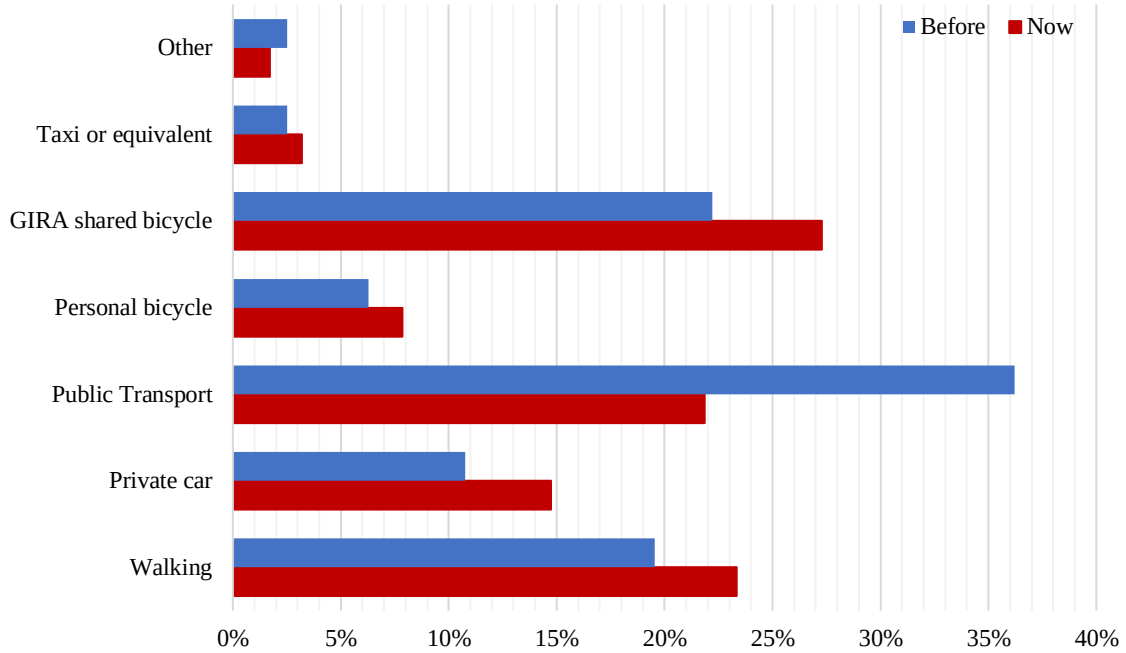


Figure 23 – Modal share regarding commuting before COVID-19 (N=215) and in the current situation (N=176)

We have also explored possible differences regarding the main modes of transport for commuting between the different groups of *GIRA* users (Table 11). Table 11 reveals that more than half of former *GIRA* users no longer commute in the current situation (51.7%). In contrast, most of the respondents that use *GIRA* during COVID-19, either old or new users, continue to commute.

Regarding the respondents that continue to commute, we observe considerable differences on the main modes of transport between the different user groups. Former users have massively increased the modal share of private car (increasing from 13.4% to 56.5%) at the expense of *GIRA* and PT, while also increasing the share of personal bicycle but at a lower scale. In contrast, while the new users have also significantly decreased the modal share of PT (decreasing from 60.8% to 28.3%), they have mostly shifted to *GIRA* (increasing to 30.2%). Comparatively to the former and new users, the modal share changes of the respondents who were users before and during COVID-19 were much less pronounced, with a decrease in PT and an increase in most of the other modes (particularly *GIRA* and walking).

Table 11 – Percentage of respondents who continue or no longer continue to commute during COVID-19 and the respective modal share for commuting before and during COVID-19, considering all users as well as the different subgroups

	All Users (N=215)		Former users (N=29)		Users before and during COVID-19 (N=154)		New users (N=32)	
	Before	Now	Before	Now	Before	Now	Before	Now
Continues to commute	81.9%		48.3%		89.0%		78.1%	
No longer commutes	18.1%		51.7%		11.0%		21.9%	
<i>Walking</i>	19.5%	23.3%	19.5%	21.7%	20.7%	24.2%	13.9%	18.9%
<i>Private car</i>	10.8%	14.7%	13.4%	56.5%	9.8%	12.1%	12.7%	13.2%
<i>Public Transport</i>	36.2%	21.9%	31.7%	4.3%	32.2%	22.1%	60.8%	28.3%
<i>Personal bicycle</i>	6.3%	7.9%	3.7%	8.7%	7.6%	8.2%	2.5%	5.7%
<i>GIRA shared bicycle</i>	22.2%	27.3%	25.6%	4.3%	24.7%	28.4%	6.3%	30.2%
<i>Motorcycle</i>	1.6%	1.7%	1.2%	0.0%	2.0%	2.1%	0.0%	0.0%
<i>Taxi or equivalent</i>	2.5%	3.2%	3.7%	4.3%	2.3%	3.0%	2.5%	3.8%
<i>Other</i>	0.9%	0.0%	1.2%	0.0%	0.8%	0.0%	1.3%	0.0%

4.4.1.4. BSS MULTIMODALITY

Another aspect of the travel behaviour potentially affected by the coronavirus is the multimodality of *GIRA* trips. Figure 24 presents the share of trips conducted only by *GIRA* or in combination with other modes before the pandemic and in the current situation.

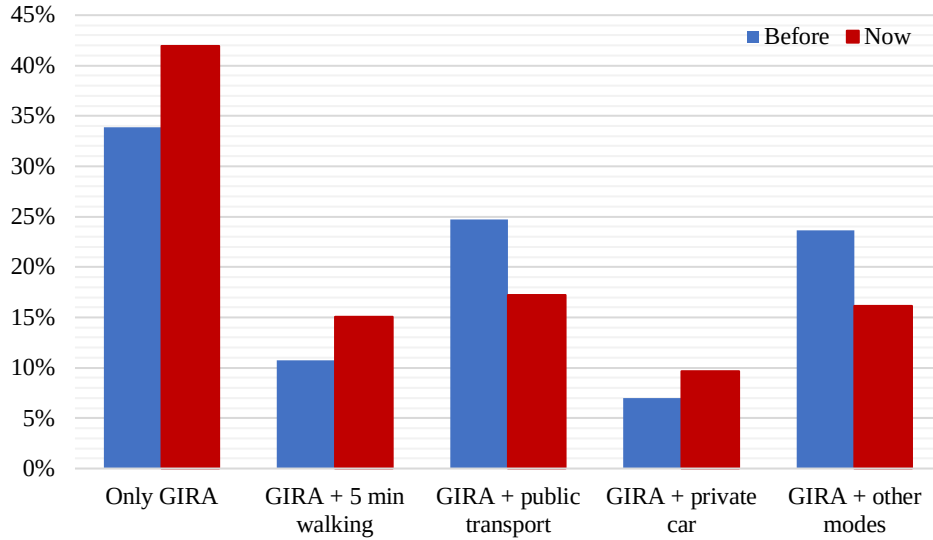


Figure 24 – Multimodality of *GIRA* before COVID-19 (N=183) and in the current situation (N=186)

We can observe that before the pandemic, 66.5% of *GIRA* trips were conducted in combination with other modes, particularly public transport. However, with the pandemic the number of trips conducted in combination with other modes has decreased to 58.9%, while trips conducted using only *GIRA* has increase from 33.5% to 41.1%. Even though PT continues to be the most common mode combined with *GIRA*, its share is now much closer to walking trips (longer than 5 min) with a share of 17.2% versus 15.1%, respectively. The share of respondents combining *GIRA* trips with their private car has also increased from 7% to 9.7%.

4.4.1.5. MODAL SHIFT DYNAMICS

By asking respondents which mode of transport they would use in their most frequent trip with *GIRA* if the BSS did not exist, we were able to analyse the modal shift dynamics from before the pandemic to the current situation (Figure 25).

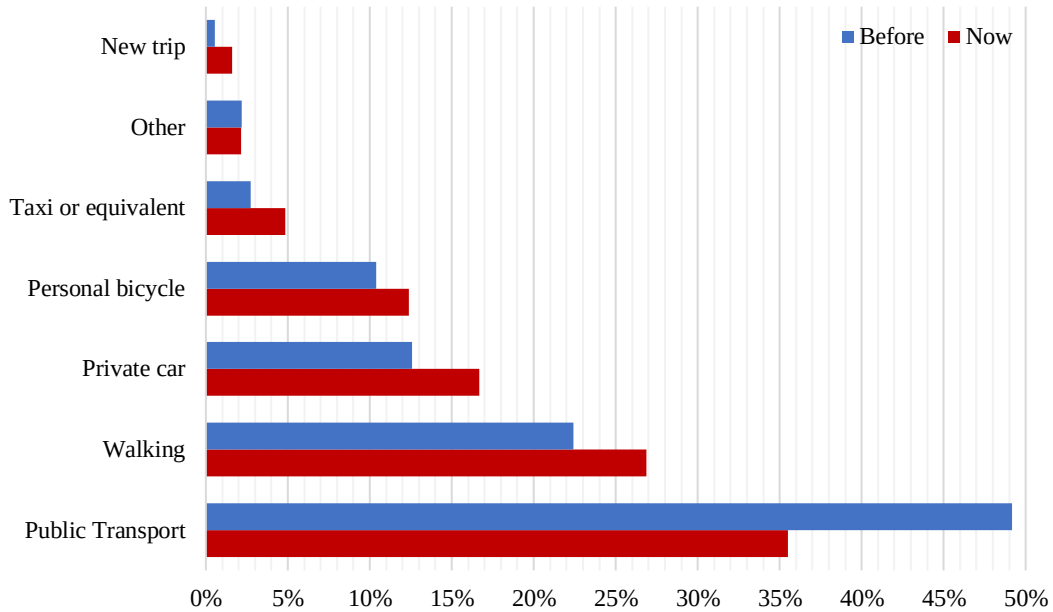


Figure 25 – Modal shift to *GIRA* before COVID-19 (N=183) and in the current situation (N=186)

Before the coronavirus pandemic, by far the most replaced mode was public transport with 49.2% of the users reporting shifting from PT to *GIRA*, followed by walking (22.4%) and private car (12.6%). Interestingly in the current situation, although the most replaced mode continues to be PT, its share has significantly decreased to 35.5%, whereas modal shift has increased in virtually all other modes, particularly walking (increasing to 26.9%) and private car (increasing to 16.7%).

To better understand such modal shift dynamics, we developed a Sankey diagram of the subsample of respondents who were users before COVID-19 and continue to currently use as they allow us to directly compare the modal shift from each particular mode between the two time periods. Figure 26 presents the Sankey diagram, where on the left we have the percentage of modes replaced before the coronavirus and on the right we have the percentage of modes replaced in the current situation. The lines represent the total direct shift from a mode before the coronavirus to a mode in the current situation, the thicker the line the bigger the share of the modal shift.

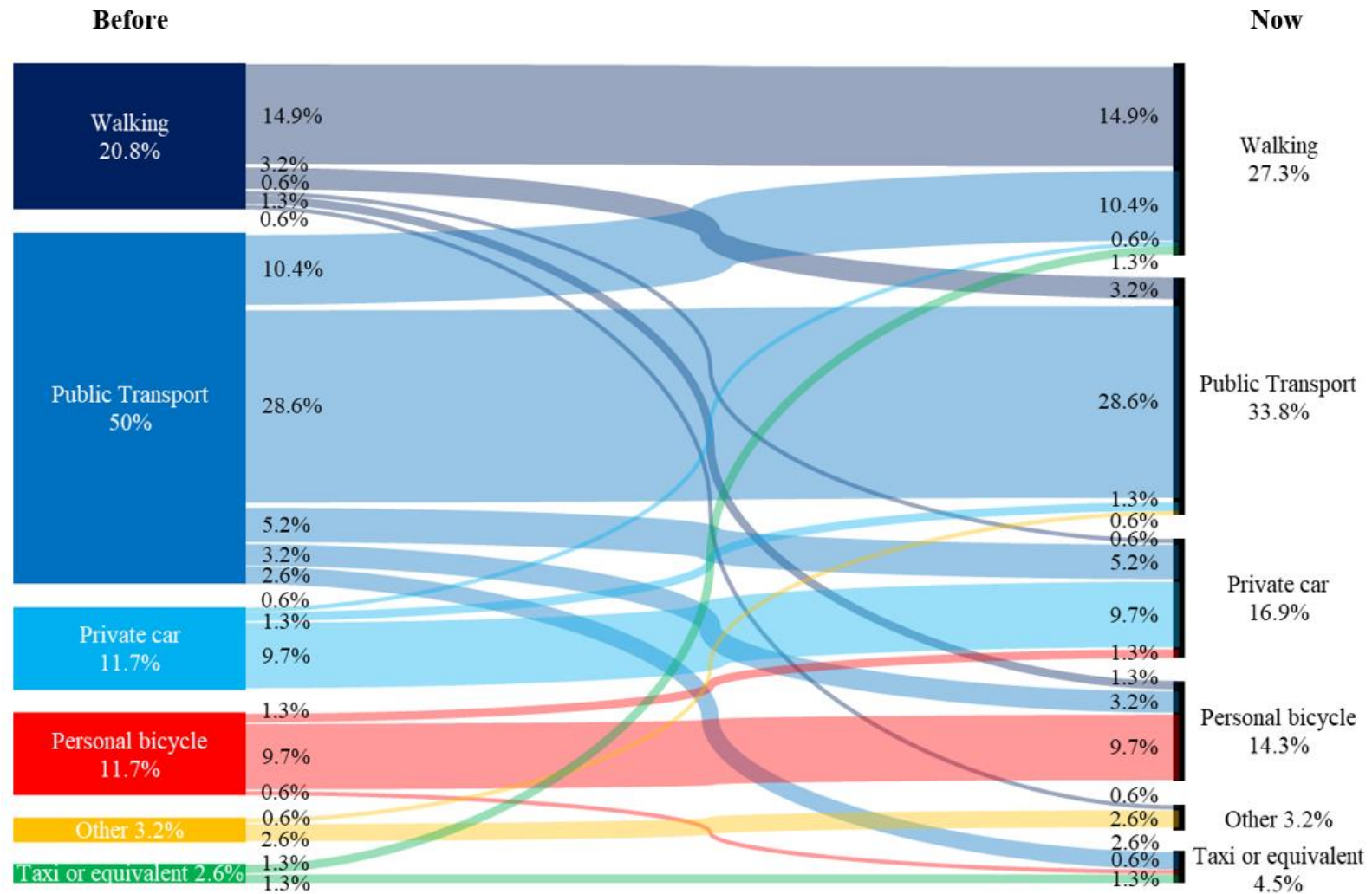


Figure 26 – Sankey diagram representing the modal shift dynamics (responses to the question “which mode of transport would you have used if GIRA did not exist?”) of the respondents who were users before COVID-19 and continue to currently use GIRA (N=154)

The Sankey diagram reveals that while most users report the same mode being replaced by *GIRA* before and during the coronavirus, 21.4% of the total amount has switched from replacing PT to replacing other modes, particularly walking (10.4%), private car (5.2%) and personal bicycle (3.2%). There are two possible explanations for such shift from public transport. First, there was a change in the trip purpose of using *GIRA*, with a small decrease in commuting trips and an increase in trips related to shopping or leisure. However, as we have previously seen in Figure 22, only a small percentage of users has decreased their share of commuting trips (from 39% to 33% in the case of the respondents who were users before COVID-19 and continue to currently use *GIRA*). We hypothesize that this considerable shift from public transport may be related to some respondents no longer considering PT a viable transport alternative as they no longer feel safe due to the coronavirus. The next sections, which will focus on the motivations for using *GIRA* and perceived risks of using different modes will shed some light in this supposition.

4.4.2. MOTIVATIONS AND SAFETY PERCEPTIONS

4.4.2.1. CHANGES IN MOTIVATIONS FOR USING *GIRA*

By using a 5-point Likert scale, we asked respondents to classify the importance in their decision to use *GIRA* of accessing or avoiding PT, maintaining a social distance, as well as health concerns and fitness improvements. Moreover, motivations related to low traffic speeds and the provision of cycling lanes along the trip were also evaluated as the pandemic and subsequent policy responses may have led to changes in these motivations. Figure 27 presents the variation on the level of importance of the motivations to use *GIRA* that could have been affected by the pandemic.

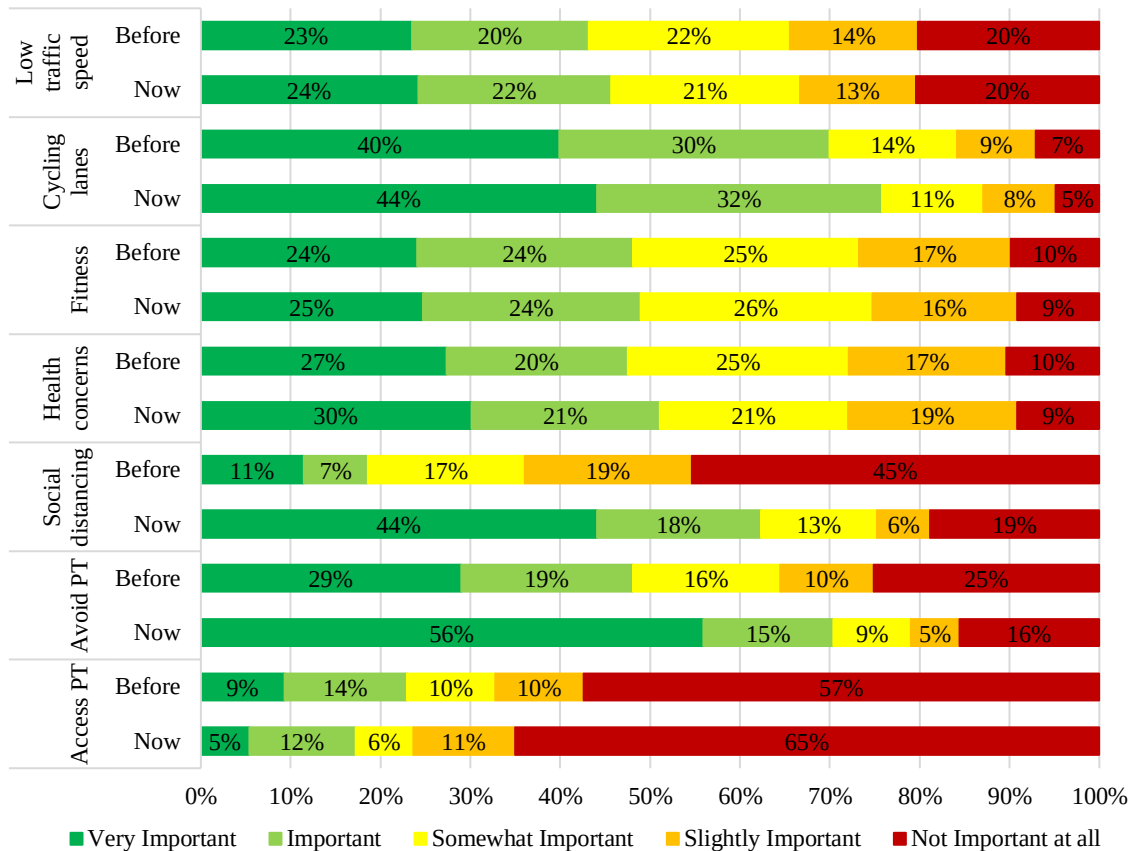


Figure 27 – Variation on the importance of motivations to use *GIRA* that could have been affected by COVID-19 before the pandemic (N=183) and in the current situation (N=186)

The figure reveals a considerable change. Firstly, the importance of maintaining a social distance has greatly increased in the current situation with 44% of the respondents now considering it to be very important comparatively to only 11% before the pandemic. Furthermore, the motivations related to public transport have also changed. Firstly, the importance of using *GIRA* to access PT has decreased with only 17% of the respondents now considering it to be important or very important comparing to 23% before the pandemic. Secondly, the importance of using *GIRA* to avoid PT has dramatically increase with now 56% of the respondents considering this motivation to be very important, when before the pandemic only 29% had such opinion. The remaining motivations have remained fairly stable with a slight increase in the importance of cycling lanes serving the trip with the percentage of respondents considering it important or very important increasing from 70% to 76%.

To better understand such differences, we have conducted additional analyses focusing on assessing the motivations of the subsample of respondents who were users before COVID-19 and continue to currently use *GIRA*. As we have ordinal and paired data, we have employed Wilcoxon Signed Rank tests to assess if the differences on the motivations' importance before the coronavirus pandemic and in the current situation were statistically significant. The results of the tests, as well as the variation on the importance of each motivation are presented in Table 12.

The Wilcoxon Signed Rank tests reveal a statistically significant difference between the period before the coronavirus pandemic and now in the motivations related to accessing and avoiding PT as well as maintaining a social distancing, which are supported by substantial percentual changes. Moreover, for this subgroup of respondents that were users before COVID-19 and continue to currently use the system, the difference on the importance of health concerns between the two periods was also statistically significant, with a 13.9% percentual increase on the number of respondents considering it very important and a 15.8% decrease on the number considering it not important.

Table 12 – Variation on the importance of motivations to use *GIRA* that could have been affected by COVID-19, as well as the results of the Wilcoxon Signed Rank tests and associated significance, of the respondents who were users before COVID-19 and continue to currently use (N=154)

Motivations	Percentual change (%)					Wilcoxon Signed Rank test	Differences significant at $p < .05$ (test)
	<i>Very Important</i>	<i>Important</i>	<i>Somewhat Important</i>	<i>Slightly Important</i>	<i>Not Important at all</i>	<i>Z</i>	
<i>Access PT</i>	-33.3%	-15.0%	-10.0%	14.3%	7.4%	-2.294	Yes
<i>Avoid PT</i>	124.3%	-10.7%	-55.6%	-50.0%	-43.2%	-6.171	Yes
<i>Fitness</i>	6.7%	-10.3%	10.5%	-3.4%	-5.6%	-.610	No
<i>Health concerns</i>	13.9%	-9.7%	2.6%	0.0%	-15.8%	-2.144	Yes
<i>Cycling lanes</i>	4.8%	2.1%	-9.5%	-7.1%	-10.0%	-1.272	No
<i>Low traffic speed</i>	2.8%	0.0%	6.3%	-9.1%	-3.3%	-1.186	No
<i>Social distancing</i>	392.9%	300.0%	-16.7%	-65.6%	-61.5%	-8.232	Yes

4.4.2.2. PERCEIVED SAFETY OF DIFFERENT MODES OF TRANSPORT IN LISBON

The coronavirus pandemic, not only due to its infectious characteristics but also to its consequences in the dynamics of the transport system, could have changed the perceived risk of the respondents regarding the different modes of transport that are available to them. To try to capture such impact, we asked the respondents to compare, through a Likert-scale, their perception of safety in using several modes of transport in Lisbon before the pandemic and in the current situation. The results are represented in Figure 28.

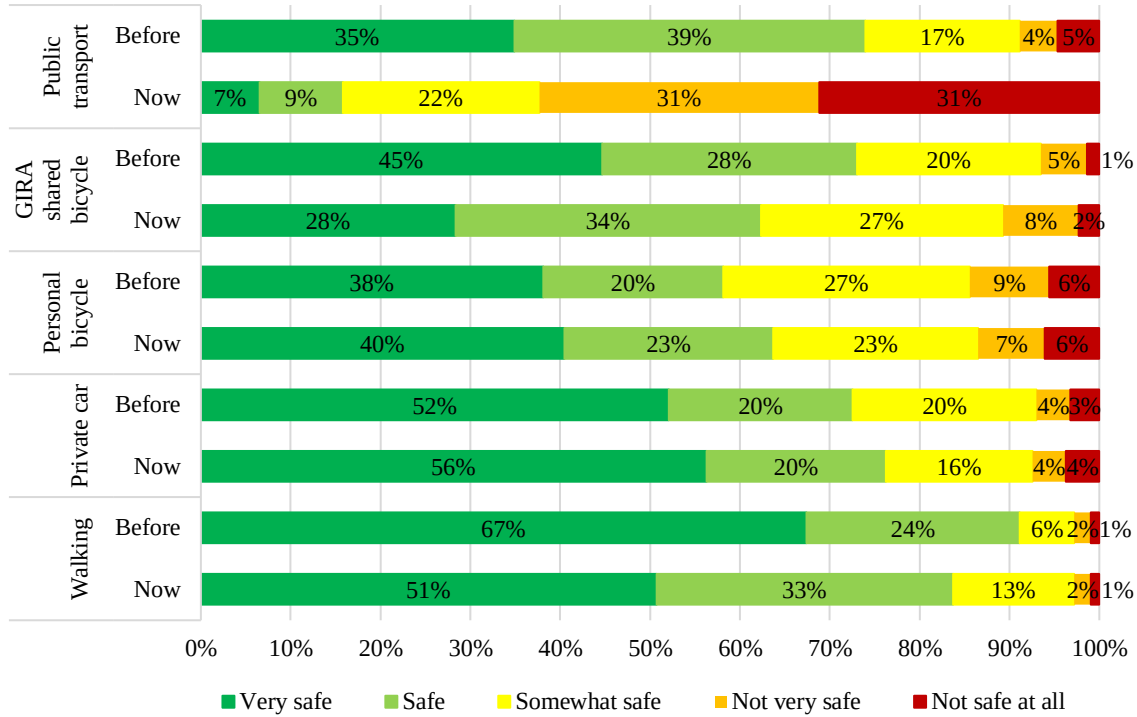


Figure 28 – Safety perceptions of using different modes of transport before COVID-19 and in the current situation (N=215)

The figure reveals very remarkable insights on the perceived safety of the different modes by the respondents. Before the pandemic, the perceived safety of most modes was similar, although with a clear advantage for walking with 91% of the respondents considering it to be safe or very safe. The exception was personal cycling, which was the mode with the least perceived safety pre-pandemic with only 58% of the respondent considering it to be safe or very safe. In contrast, 73% of users considered *GIRA* to be safe or very safe. With the coronavirus pandemic, the perceived risk has changed, particularly regarding PT which witnessed a dramatic decrease on the safety perceptions towards it. While before the pandemic 74% the respondents considered using PT to be safe or very safe, in line with the percentage of using a private car (73%) or *GIRA* (72%), now that percentage is only 16%. Although in a smaller scale, the perceived safety of *GIRA* and walking has also decreased to, respectively, 62% and 84% of the respondents considering those modes to be safe or very safe. In contrast, the perceived safety has increased both regarding using a private car and a personal bicycle, with now 76% and 64% of respondents considering those modes to be safe or very safe, respectively.

To assess if such differences in the perceived safety were statistically different between before the pandemic and now, we conducted Wilcoxon Signed Rank tests. The results of the tests and the percentual changes in the perceived safety of the different modes between the two periods are presented in Table 13. The tests reveal statistically significant differences in the perceived safety regarding walking, *GIRA* shared bicycles and public transport.

Lastly, we explored possible statistically significant differences on the safety perceptions of using *GIRA* between the users who stopped using the system due to COVID-19 and the new users who have joined during the pandemic. To accomplish this, we applied Mann-Whitney U tests (as we now have two independent groups), with its results as well as the percentual differences in perceived perceptions between the two groups represented in Table 14.

The results reveal that before the coronavirus pandemic there was not a statistically significant difference in the perceived safety regarding *GIRA* between the two groups. But in the current situation we now find a statistically significant difference between the two groups, with the new users having a much more positive perceived safety towards *GIRA* than the former users (a 450% and 600% percentual change in considering *GIRA*, respectively, very safe and safe).

Table 13 – Variation in the safety perception of using different modes of transport in Lisbon before the COVID-19 pandemic and in the current situation, as well as the results of the Wilcoxon Signed Rank test and associated significance (N=215)

Modes of transport	Percentual change (%)					Wilcoxon Signed Rank test	Differences significant at $p < .05$ (test)
	Very safe	Safe	Somewhat safe	Not very safe	Not safe at all	Z	
<i>Walking</i>	-24.8%	39.2%	123.1%	0.0%	0.0%	-5.034	Yes
<i>Private Car</i>	8.0%	-2.3%	-20.5%	0.0%	14.3%	-1.930	No
<i>Personal bicycle</i>	6.1%	16.3%	-16.9%	-15.8%	8.3%	-1.946	No
<i>GIRA shared bicycle</i>	-36.5%	19.7%	31.8%	63.6%	66.7%	-4.453	Yes
<i>Public transport</i>	-81.3%	-76.2%	27.0%	644.4%	570.0%	-10.883	Yes

Table 14 – Variation in the safety perception of using *GIRA* in Lisbon between respondents who stopped using *GIRA* due to COVID-19 (N=29) and new users who joined during the pandemic (N=32), as well as the results of the Mann-Whitney U test and associated significance

<i>GIRA</i> shared bicycle	Percentual change (%)					Mann-Whitney U test		Differences significant at $p < .05$ (test)
	Very safe	Safe	Somewhat safe	Not very safe	Not safe at all	U	Z	
<i>Before</i>	33.3%	-50.0%	100.0%	0.0%	0.0%	455.5	-0.131	No
<i>Now</i>	450.0%	600.0%	-57.1%	-85.7%	-100.0%	140.5	-4.832	Yes

4.5. DISCUSSION OF THE RESULTS

This study has revealed the impacts of coronavirus to differ between BSS users. While some users have decreased or stopped using *GIRA* because of coronavirus, an almost equal number has actually increased or joined the system during the pandemic. Furthermore, the main reason for respondents decreasing or stopping using *GIRA* is not so much the fear of infection (although for some it is an important reason) but is more related to their trip purpose no longer existing, mostly due to a decrease in commuting trips.

Significant changes in the travel behaviour of *GIRA* users have also been found, particularly in their relationship with other modes of transport. First, regarding their main mode of transport in commuting trips, *GIRA* registered a share increase from 22.2% to 27.3%, now being the most chosen mode of transport at the expense of public transport which suffered a massive decline (with a 39.9% decrease). Furthermore, the share of trips conducted only by *GIRA* has increased, while the percentage of trips in combination with PT has decreased. Crucially, the modal shift dynamics of bike sharing have also changed. While the most replaced mode continues to be PT, its share decreased from 49.9% to just 35.5%, with users who would previously replace PT with *GIRA* now replacing other modes such as walking, private car and personal bicycle. Such findings are supported by *GIRA* actual usage data (ridership and number of active users), which shows a significant recovery during the summer months, even surpassing 2019 usage levels. Likewise, our results are in line with the study from Teixeira and Lopes (2020), which also uncovered evidence of a modal shift from some PT users to the BSS in New York City.

Moreover, the coronavirus pandemic has increased the importance of the motivations related with maintaining a social distance during the trip and avoiding PT. For the respondents that used *GIRA* before COVID-19 and continue to currently use the system, such changes in motivations were statistically different, with also a statistically significant increase in the importance of health concerns.

Likewise, the safety perceptions of the respondents towards different modes have also changed as a result of coronavirus, with a statistically significant decrease in the safety perception of walking, public transport and *GIRA*. While before the pandemic, the perceived safety of using PT was similar to the other modes, now it is considered, by far, the most unsafe mode in Lisbon. Furthermore, the perceived safety of *GIRA* has also decreased, being now the second least safe mode, albeit with a much higher positive score than PT. In contrast, using a personal bicycle, which had the lowest perceived safety pre-pandemic is now the second perceived safest mode, behind private car. The perceived safety before the pandemic of using a personal bicycle and a shared bicycle is particularly curious as one would expect a similar perceived safety as both are ways of cycling, but respondents considered *GIRA* safer. Previous research has found evidence that bike sharing may be safer than using a personal cycling, having a lower injury risk (Woodcock *et al.*, 2014; Fishman and Schepers, 2016) and higher awareness levels from drivers (Fishman, Washington and Haworth, 2012). However, the coronavirus pandemic seems to have changed that dynamic as now a personal bicycle is considered to be safer than using a shared bicycle. Nevertheless, when comparing the safety perceptions towards *GIRA* of the respondents who stopped using the system and the users who joined *GIRA* during the coronavirus, the new users have a much more positive view of *GIRA*, which was found to be statistically significant. Overall, our findings seem to point to an emerging trend observed in other case-studies, in which bike sharing is perceived as having a lower COVID-19 infection risk than using public transport, but perceived as riskier than using private modes (Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour *et al.*, 2020).

As limitations of this study, we relied our analysis on self-reported behaviours, which may in some circumstances not reflect actual behaviour. Another limitation is related to the survey distribution method and the risk of selection bias, which was addressed by using multiple online dissemination channels and by comparing the sample with a representative survey conducted by *GIRA*'s operator.

Furthermore, our comparisons between the pre-pandemic period and nowadays depended on the use of retrospective questions, which are prone to recall biases, although the impact of coronavirus is so severe and disruptive that it is realistic to assume that people still remember their past behaviour prior to the pandemic. Finally, our survey was conducted at the beginning of the second COVID-19 wave and, as such, the behavioural insights of BSS users obtained from it may differ from similar surveys conducted during other phases of the pandemic like, for instance, during periods of low infection rates. The coronavirus pandemic is still an ongoing crisis, with possible new developments having the potential to alter the observed dynamics. Consequently, definitive results on the impacts of coronavirus will only be fully uncovered once this pandemic ends and, as such, our research should be viewed within an exploratory framework.

4.6. POLICY IMPLICATIONS AND FUTURE RESEARCH

Our findings have several implications for policymakers regarding the role of bike sharing in urban mobility during disruptive public health crises. First and foremost, we have found compelling evidence that bike sharing can act as a substitute to public transport during a pandemic such as coronavirus. Several findings support this hypothesis. We discovered an increase in the modal share of BSS in contrast to a decrease in PT regarding the main mode of transport in commuting trips as well as an increase in the percentage of single trips conducted by *GIRA*, while trips in combination with PT have decreased. At the same time, the importance of motivations connected to using BSS to avoid PT and for maintaining a social distance are now much more significant. Likewise, the perceived safety of using PT has dramatically declined, and while the perceived safety of using *GIRA* has also decrease it was in a much smaller scale (now only 16% of respondents consider PT safe in contrast with 62% still considering *GIRA* to be safe).

More importantly, our analysis of the modal shift dynamics found evidence that BSS can ameliorate a surge in car use and also prevent users from shifting from PT to the private car. While before the pandemic, 12.6% of *GIRA* users shifted from private car, now that number has climbed to 16.7%. Moreover, 10.4% of the respondents who before the pandemic would use PT if *GIRA* was not available, now would use a private car instead. As the respondents no longer feel safe in using PT due to infection fears (as evidenced by the much lower safety perceptions towards PT), they no longer consider public transport as a viable transport alternative and would choose different modes of transport if *GIRA* did not exist.

Thus, bike sharing can contribute to the resilience of urban transport systems during pandemics and other disruptive events by providing a viable alternative to the most affected modes of transport, such as PT. Indeed, emerging studies exploring BSS ridership during COVID-19 are consistently finding bike sharing to register lower ridership decreases (Bucsky, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021) and faster rebounds in comparison with PT and other modes of transport (Hu *et al.*, 2021; Wang and Noland, 2021). This is especially important within the overall push towards a more sustainable future, as bike sharing is an environmentally friendly and healthy mode of transport (Teixeira, Silva and Moura e Sá, 2021a). Furthermore, it is also very affordable, which can be especially important for people who do not feel safe in using PT but do not have any other alternative modes. For instance, *GIRA* has an annual subscription cost of 25 € (EMEL, 2019b), significantly lower than a PT pass in the city which costs around 30 € a month (VIVA, 2019). Using bike sharing is also much more affordable than buying a personal bicycle, particularly an e-bike, which *GIRA* provides. Even for those who could afford a new bicycle, it was notorious during this pandemic the difficulty in buying a bicycle due to a surge in demand (BBC News, 2020), including in Portugal (ECO, 2020). Indeed, in this study most of the other reasons

for decreasing or stopping using *GIRA* specified by respondents were actually related to a lack of available shared bicycles, particularly e-bikes.

Still, the perceived safety of using *GIRA* has decreased, with some users quitting the system due to infection fears. In that sense, special attention should be given for enhancing and publicizing the cleaning of shared bicycles and other surfaces that involve touch, and to try to avoid agglomerations of users near the docked stations, perhaps by deploying smaller BSS stations around the same area instead of a single large station. Even though shared bicycles could be a potential source of infection, the risk should be much lower than enclosed and often overcrowded PT systems, allowing social distancing to be maintained in most of the trip.

As future research, these results need to be compared with other international BSS in operation to assess possible similarities and differences. It would be especially useful to assess the performance of different types of bike sharing, particularly docked versus *dockless* systems, as well as other types of shared micro-mobility systems such as e-scooter sharing. Likewise, follow-up longitudinal studies could be conducted by employing multiple survey waves throughout the different phases of the pandemic, for instance, comparing the behaviour of BSS users during the peak of a COVID-19 wave versus during a period of low infection rates. Moreover, further research should focus on analysing different subgroups of BSS users regarding behaviour changes as a result of coronavirus. As this research has shown, the responses of BSS users to the coronavirus were very different, with some users decreasing or stopping using *GIRA* but others actually increasing or joining the system. More in-depth qualitative approaches, such as focus groups or semi-structured interviews, could deliver important insights into the individual behavioural changes provoked by coronavirus on BSS users, particularly regarding their motivations and attitudes.

The coronavirus pandemic presents several challenges for our transport systems but also opportunities such as potentially opening a short window for structural changes towards a more sustainable future. Indeed, several countries have announced that a substantial share of their economic recovery funds will be allocated to sustainable initiatives (European Commission, 2020). Yet, PT ridership levels will continue to be at historical lows as long as coronavirus remains a threat, and perhaps even beyond that timeline. Consequently, bike sharing, and cycling in general, should be seen as an alternative to public transport and car during this pandemic, potentially preventing PT users for shifting to private cars, which would contribute to minimize the detrimental consequences of a surge in car use.

5.

THE MOTIVATIONS FOR USING BIKE SHARING DURING THE COVID-19 PANDEMIC: INSIGHTS FROM LISBON

This chapter presents an integral reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (2021) ‘The motivations for using bike sharing during the COVID-19 pandemic: Insights from Lisbon’, Transportation Research Part F: Psychology and Behaviour. Elsevier. 82, pp. 378–399. doi: 10.1016/j.trf.2021.09.016.”

ABSTRACT

Urban mobility has been severely impacted by the coronavirus pandemic, with public transport (PT) particularly affected due to infection risks and fears. The promotion of alternative modes of transport such as bike sharing systems (BSS) has gained a new drive as a possible way of providing an alternative to PT and limit a potential surge in private car use.

In this study, we provide insights on the motivations for using bike sharing during the COVID-19 pandemic through a survey to the BSS users of Lisbon (entitled *GIRA*). Before the coronavirus pandemic, the most influential motivations were those connected to the BSS’ *Service Coverage & Quality* (such as the convenient location of BSS stations near the users’ destinations or the availability of shared e-bikes) as well as to the *Personal Interests & Well-being* of BSS users (namely the pleasure of cycling as well as the perceived environmental and health benefits). With the emergence of the COVID-19 pandemic, although the motivations of *Service Coverage & Quality* continue to be the most valued by respondents, the motivations associated with using BSS to avoid PT and to maintain a social distance during the trip are now as important as the motivations linked to *Personal Interests & Well-being*. Furthermore, new users who have joined bike sharing during COVID-19 give more importance to the *Social Influence* (such as seeing other people using the system or the influence of their social circle) comparatively to those who were already users before the pandemic and continue to use BSS.

This research provides evidence on the importance of bike sharing to the resilience of urban transport systems, particularly during disruptive public health crises. It supports that BSS should continue to operate during the coronavirus pandemic as such systems offer a transport alternative to PT that is perceived to be capable of preserving a physical distance.

KEYWORDS: Coronavirus; Urban mobility; Bike sharing; Motivations; Factor analysis

5.1. INTRODUCTION

The severity of the coronavirus pandemic and the subsequent policy responses to limit its spread have disrupted nearly every aspect of normal life, with physical interactions now considered as an extremely high-risk behaviour due to potential COVID-19 infection. As a consequence, mobility has been severely restricted in order to limit social contacts, leading to massive reductions in travel demand. For instance, the Netherlands registered a 55% drop in the number of trips conducted comparatively to 2019, with almost 80% of the population reducing their outdoor activities (de Haas, Faber and Hamersma, 2020). Similar impacts were observed worldwide, in all countries that implemented major lockdowns (Bucsky, 2020; Google, 2020; Hadjidemetriou *et al.*, 2020; Sharifi and Khavarian-Garmsir, 2020).

Public transport (PT) has been particularly affected by the pandemic due to infection risks. With the potential transmission risk posed by having large numbers of people in close proximity inside enclosed and frequently overcrowded vehicles, governments have discouraged the PT use during COVID-19 (GOV.UK, 2020). This has caused unprecedented ridership drops in PT systems across the world (Gkiotsalitis and Cats, 2020). For example, New York City's subway, one of the biggest subway systems in the world, suffered a 90% ridership drop during the height of the city's lockdown (Teixeira and Lopes, 2020), with ridership still 70% below pre-pandemic levels even after the lockdown being lifted (Wang and Noland, 2021). Not only PT ridership has felt to historic lows, but also the perceived risk of infection has led to a widespread increase in the public's aversion towards PT usage (Gkiotsalitis and Cats, 2020). In the Netherlands, more than 90% of respondents from a representative survey have now negative attitudes towards PT, with the study showing an association between the fear of becoming infected and a preference for personal modes of transport (de Haas, Faber and Hamersma, 2020). Likewise, in Chicago a similar survey found 93% of the respondents to consider PT as having a medium to extreme risk of infection (Shamshiripour *et al.*, 2020). In contrast, the use of the private car has been much less affected than PT, with lower mobility decreases and lower perceived risks of infection (Sharifi and Khavarian-Garmsir, 2020). For comparison, in the previously mentioned study from Chicago, 86% of the respondents considered car travel as safe (Shamshiripour *et al.*, 2020). Consequently, and bearing in mind that PT ridership is expected to continue to be affected throughout the duration of the pandemic (and, perhaps, even after), there is a risk of a modal shift from public transport to the car. Such shift would exacerbate the numerous negative externalities associated with car use (Douglas *et al.*, 2011).

Cycling could be a potential alternative both to PT and car use during a pandemic such as COVID-19, capable of providing an efficient, affordable, environmentally friendly, and healthy transport alternative (Ellison and Greaves, 2011; Rabl and de Nazelle, 2012; Handy, van Wee and Kroesen, 2014). Cycling becomes a particularly attractive alternative within the COVID-19 context, characterized by the geographical limitations on travelling, where short trips at the local level have gained a new relevance (de Haas, Faber and Hamersma, 2020) and on which the bicycle is especially competitive (J. Dekoster, 1999; Ellison and Greaves, 2011). Of the several measures promoting cycling use, arguably amongst the most notorious is the implementation of bike sharing systems (BSS) (Pucher and Buehler, 2017). Several benefits have been linked to BSS, particularly their ability to increase the number and diversity of cyclists, foster synergies with PT (including by alleviating some of the pressure from overcrowded services) and to be a competitive transport alternative capable of reducing car use (Teixeira, Silva and Moura e Sá, 2021a).

As such, it is important to investigate how are bike sharing systems performing during the coronavirus pandemic, including on how the impacts of COVID-19 have affected the behaviour of BSS users. A crucial research direction is to explore if the coronavirus has changed the reasons for using bike sharing. For instance, faced with a perceived risk of infection for using public transport, users may now value much more using bike sharing as an alternative to PT. It is vital to investigate the motivations for using

bike sharing during pandemic health crisis such as the coronavirus not only to design systems better prepared to these types of disruptive events, but also to gain insights on the potential contribution of BSS towards increasing the resilience of urban transport systems.

The present study builds upon the existent research on the motivators to BSS use by assessing motivations related to the impacts of COVID-19 and comparing their importance with the other known facilitators of BSS usage prior to the pandemic. Furthermore, motivations linked to new BSS innovations, namely the availability of shared e-bikes that provide additional advantages such as less effort to cycle or increase trip's range, are also included. Consequently, and by employing a survey to the BSS users of Lisbon (entitled *GIRA*), this study aims at providing evidence to the following research question:

- *What are the most important motivations for using bike sharing before and during COVID-19?*

Several researchers expect that this pandemic will lead to long term changes in travel behaviour such as a greater preference for private modes of transport over PT or a decrease in travel demand due to higher levels of teleworking (de Haas, Faber and Hamersma, 2020; De Vos, 2020; Shamshiripour *et al.*, 2020; Sharifi and Khavarian-Garmsir, 2020). Effective policymaking could determine if the potential structural changes induced by COVID-19 will contribute to more resilient and sustainable transport systems namely by promoting active modes of transport. On the contrary, the absence of decisive policies during this pandemic could lead to a more unsustainable future where current decarbonization efforts fail due to a major surge in car use. The insights from this study may support policymakers ensuring that the first scenario becomes a reality by providing evidence on how BSS can meet the mobility needs of citizens during disruptive events such as the current coronavirus pandemic.

5.2. LITERATURE REVIEW

5.2.1. MOTIVATIONS AND BARRIERS FOR USING BIKE SHARING BEFORE COVID-19

Amongst the most consistent findings from the literature is convenience being one of the major motivations for joining bike sharing (Ricci, 2015; Fishman, 2016). For instance, Fishman *et al.* (2014) quantified the motivators and barriers for joining the BSS of Brisbane and Melbourne (Australia) by surveying users and non-users. Among users, convenience was the most important factor for joining, followed by having BSS stations close to the workplace (which is in itself also associated with convenience), while to non-users car convenience was one of the main barriers for joining (Fishman *et al.*, 2014). The existence of BSS stations close to residential and work locations is crucial on the decision to use bike sharing (Bachand-Marleau, Lee and El-Geneidy, 2012; Fishman *et al.*, 2015; Raux, Zoubir and Geyik, 2017; Hosford *et al.*, 2018). For example, in their qualitative study of the main barriers and facilitators for BSS use in Brisbane, Fishman, Washington and Haworth (2012) found the existence of BSS stations close to home and workplaces paramount on the decision of non-users to consider using BSS. Convenience is also closely connected to travel time savings (Fishman *et al.*, 2014), which is often cited as one of the main perceived personal benefits of BSS (Ricci, 2015). For instance, in New York City, considering BSS the fastest mode of transport was amongst the factors associated with frequent users (Reilly, Noyes and Crossa, 2020). Equally, in the surveys of London's BSS conducted by TfL (2011), the main motivation, among members, to join the scheme was BSS being quicker than their previous mode.

Another factor influencing BSS adoption is the easiness of using the system itself. Features such as the amount of time and effort needed to sign up to use the system or even the operating hours can influence the decision to join or not bike sharing. In fact, among the main identified barriers for using Brisbane's

BSS in the focus groups conducted by Fishman, Washington and Haworth (2012) was the lengthy sign up process and the system being only available between 5 a.m. and 10 p.m. The fact of the system not being opened 24/7 was especially criticized as it hindered the possibility of providing a mobility option when PT was less available (Fishman, Washington and Haworth, 2012). Likewise, the perceived ease of using bike sharing has been identified as positively influencing attitudes and intentions of use (Chen and Lu, 2016; Wu *et al.*, 2019).

The affordability and the flexibility provided by shared bikes have also been positively correlated with influencing the decision to use BSS. Financial savings are often cited as a reason for shifting to BSS (TfL, 2011; Ma *et al.*, 2020; Reilly, Noyes and Crossa, 2020), especially among lower-income groups (Ogilvie and Goodman, 2012; Fishman, 2016; McNeil, Broach and Dill, 2018; Reilly, Noyes and Crossa, 2020) and students (Molina-García *et al.*, 2015). Not owning a bicycle (Hosford *et al.*, 2018) or using bike sharing to avoid the inconveniences of personal cycling such as parking, theft and maintenance are also among the reasons stated by users for switching to BSS (Bachand-Marleau, Lee and El-Geneidy, 2012; Ma *et al.*, 2020).

Moreover, using BSS to access PT is important for a proportion of users. Murphy and Usher (2015) revealed that 39% of users of Dublin's BSS were integrating BSS with other modes, of which 56.3% were combining with rail and 35.2% with bus. Similarly, Bachand-Marleau, Lee and El-Geneidy (2012) found, among others, the combination of cycling and PT trips to be a significant predictor for BSS use. These results are echoed by the analysis of London's BSS, with the surveys conducted by TfL (2011) showing that between 39% (wave 1) and 41% (wave 2) of respondents used BSS as part of a longer trip, mostly combining with PT (by order of use: train, subway and bus).

Environmental and health concerns are as well strong indicators of BSS usage behaviours (Fishman *et al.*, 2014; Hosford *et al.*, 2018; Wang *et al.*, 2018; Cerutti *et al.*, 2019). For instance, in the users' surveys conducted by TfL, the fact of BSS being perceived as an healthier option is one of the main reasons for using it, with environmental concerns, although in a lesser degree, also mentioned (TfL, 2011). Furthermore, perceived environmental and health benefits have been found to positively influence intentions to use BSS among users and non-users (Chen and Lu, 2016; Kim *et al.*, 2017; Wang *et al.*, 2018). For example, in Taipei (Taiwan), Chen and Lu (2016) found that the green perceived usefulness, translated in emission and congestion reductions as well as health benefits, positively influenced green intentions of use in both users and non-users.

Interestingly, fun and enjoyment in using bike sharing is also highly regarded by its users (Fishman *et al.*, 2014; Chen, 2016), especially among casual users (TfL, 2011), with perceived fun to use positively influencing usage intention towards BSS (Wu *et al.*, 2019). This is in line with other studies of cycling in general, where cyclists find their commute more relaxing and exciting comparatively to other modes (Heinen, van Wee and Maat, 2010), with the enjoyment of cycling having a great influence on the final decision to cycle (Heinen and Handy, 2012).

Lastly, having a supportive social environment fosters the adoption and usage of bike sharing (Wang *et al.*, 2018; Chen, van Lierop and Ettema, 2020). The trendy status (Bachand-Marleau, Lee and El-Geneidy, 2012), as well as seeing people using the system positively influence BSS use (Fishman, Washington and Haworth, 2012). Indeed, the prevalent view of the focus groups in Fishman, Washington and Haworth (2012) study was that seeing other people in the city using the BSS was the best possible promotion.

However, there are important barriers that hinder BSS usage. First, in countries with mandatory helmet laws, the need to wear helmets when using a BSS has been associated with lower usage rates, although the provision of helmets at BSS stations seems to alleviate this problem (Ricci, 2015; Fishman, 2016).

Furthermore, the fact of many of these systems requiring the use of smartphones or credit/debit cards constitutes a barrier for disadvantaged groups (low-income, less educated and ethnic minorities), leading to an under-representation of such groups among BSS users (Ogilvie and Goodman, 2012; Goodman and Cheshire, 2014; Ursaki and Aultman-Hall, 2016; McNeil, Broach and Dill, 2018).

More importantly, safety concerns are among the main barriers to BSS use (Fishman, 2016), which not only affects bike sharing but also cycling in general (Heinen, van Wee and Maat, 2010; Heinen and Handy, 2012). For instance, in the focus groups study conducted by Fishman, Washington and Haworth (2012) of non-cyclists, cyclists and BSS users, safety emerged as a key concern for all groups. Two major safety concerns were identified: the lack of cycling infrastructure (such as cycling lanes or paths) as well as dangerous drivers' behaviour, with non-users being particularly sensitive to the lack of dedicated cycling infrastructure (Fishman, Washington and Haworth, 2012). This is corroborated by the existence of cycling infrastructure, namely bike lanes, being positively associated with the generation of BSS trips (Buck and Buehler, 2012; Noland, Smart and Guo, 2016). Increasing the safety of using bike sharing, by providing cycling infrastructure or implementing traffic calming measures, could also address the gender imbalance among BSS users, which is skewed towards men (Ricci, 2015; Fishman, 2016), as female users were found to be more sensitive to traffic conditions (Wang and Akar, 2019). Indeed, in countries such as the Netherlands with extensive dedicated cycling networks and where cycling injury rates are very low, women cycle as much as men (Pucher and Buehler, 2008).

5.2.2. USE OF BIKE SHARING DURING COVID-19

Most studies explored the resilience of bike sharing to the coronavirus pandemic by analysing ridership data. As in virtually all other modes of transport, BSS registered a ridership decline during the lockdown periods (Bucsky, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021; Shang *et al.*, 2021). However, evidence also points to bike sharing sustaining lower ridership drops (Bucsky, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021), an increase in its average trip duration (Teixeira and Lopes, 2020; Hu *et al.*, 2021; Padmanabhan *et al.*, 2021; Shang *et al.*, 2021) and faster recoveries comparatively to other modes (Hu *et al.*, 2021; Wang and Noland, 2021). Taking advantage of the extensive open data policy of New York City, Teixeira and Lopes (2020) compared the performance of the city's subway and bike sharing systems during March 2020 at the height of the COVID-19 lockdown. Teixeira and Lopes (2020) found evidence demonstrating BSS to be more resilient than the subway to the COVID-19 pandemic, registering lower ridership drops and an increase in BSS trips' average duration, suggesting a possible modal shift from some subway users to bike sharing. These findings are supported by Pase *et al.* (2020). Also analysing the performance of New York City's bike sharing and subway systems during March 2020, Pase *et al.* (2020) observed that while the decline of subway ridership was felt throughout all the city's boroughs, there were boroughs where BSS ridership actually increased, particularly in the areas served by subway stations. Extending this analysis on the same case-study to the period after lockdown, Wang and Noland (2021) found the BSS ridership to recover to the pre-pandemic levels, while subway ridership was still just 30% of the levels registered before COVID-19.

The resilience of bike sharing to the COVID-19 pandemic comparatively to other modes of transport was also observed in other cities. In Budapest (Hungary), Bucsky (2020) found bike sharing to register the lowest ridership drop (2%) comparatively to an overall 57% decrease in mobility, with PT being the most affected mode (80% drop). Likewise, in Chicago, Hu *et al.* (2021) observed that, even though all modes registered severe ridership drops during the height of the lockdown, bike sharing had the fastest recovery not only when comparing with PT but also comparatively to walking and driving.

Complementing the findings from analysing BSS trip data, a smaller number of studies employed travel behaviour surveys aimed at users of bike sharing. A emerging pattern from such surveys is that bike sharing is considered to be safer regarding the infection risk of COVID-19 than using PT or taxi, but perceived as less safe than using personal modes such as the car and walking (Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour *et al.*, 2020). Nikiforiadis, Ayfantopoulou and Stamelou (2020), explored the safety perceptions of users from a small BSS in Thessaloniki (Greece). The study found that the respondents who considered BSS as safe had higher odds of using the system, leading the authors to highlight the need for BSS operators to implement specific measures aimed at decreasing the infection risk of COVID-19 (Nikiforiadis, Ayfantopoulou and Stamelou, 2020). However, Jobe and Griffin (2021) reveal that in addition to implementing safety measures, operators also need to better communicate their COVID-19 prevention efforts in order to increase the attractiveness of bike sharing during the pandemic. Analysing the BSS of San Antonio (USA), Jobe and Griffin (2021) found that even though the system's operator had implemented several measures to minimize the COVID-19 transmission risk of using bike sharing, only 57% of the surveyed respondents were aware of such efforts.

Thus, most of the existing literature exploring the impacts of COVID-19 on bike sharing focus on analysing trip data provided by the BSS operators. Only a few studies explore changes in the individual behaviour of BSS users due to COVID-19 and, of those, most focus on observing changes in travel behaviour and exploring the safety perception of using BSS comparatively to other modes. To the best of our knowledge only one study has so far explored the factors for using bike sharing during the COVID-19 period (Bergantino, Intini and Tangari, 2021), but the study did not specifically explored differences between the pre and pandemic periods and was mostly focused on non-users. As such, our study complements the current state of knowledge by providing a unique view on the motivations for using bike sharing during the COVID-19 comparatively to the pre-pandemic period. Furthermore, it introduces motivations specifically related to the coronavirus and explores differences in the motivations of different users, particularly of those who have joined BSS during COVID-19.

5.3. CASE-STUDY

5.3.1. THE MUNICIPALITY OF LISBON AND THE IMPACTS OF COVID-19

With 504,964 inhabitants, Lisbon is the most populous municipality as well as the capital of Portugal. Like the rest of the country, Lisbon is characterized by being heavily car dependent, with 45.1% of its commuting trips conducted by car, while cycling represents only 0.6% of the modal share (INE, 2018).

As in most European countries, COVID-19 has impacted Portugal through a two-wave pattern in reported cases, with a first wave occurring during the spring and a second much more devastating wave occurring at the beginning of autumn (Figure 29). The first wave started on March 2nd, 2020, with the first confirmed case of COVID-19 in Portugal (DGS, 2021). Just 16 days later, Portugal declared the State of Emergency, and the country entered a full lockdown period which ended on May 3rd. Although the COVID-19 pandemic seemed to be under control during the summer months, by the beginning of autumn the number of cases started to increase again, leading to a new State of Emergency that gradually reintroduced restrictive measures, culminating with a new full lockdown implemented at the beginning of 2021.

Figure 29, Figure 30 and Figure 31 reveal the COVID-19 impacts on the Portuguese economy and mobility trends. Figure 29 compares the monthly unemployment rate with the monthly average number of new COVID-19 daily cases throughout 2020. Although the unemployment rate has increased from

6.3% in March to 8.1% in August, stabilizing at 6.9% in December, this increase was mitigated by the temporary layoff programme implemented by the Government aimed at covering up to 100% of the employees' wages in businesses particularly affected by the pandemic (Segurança Social, 2020).

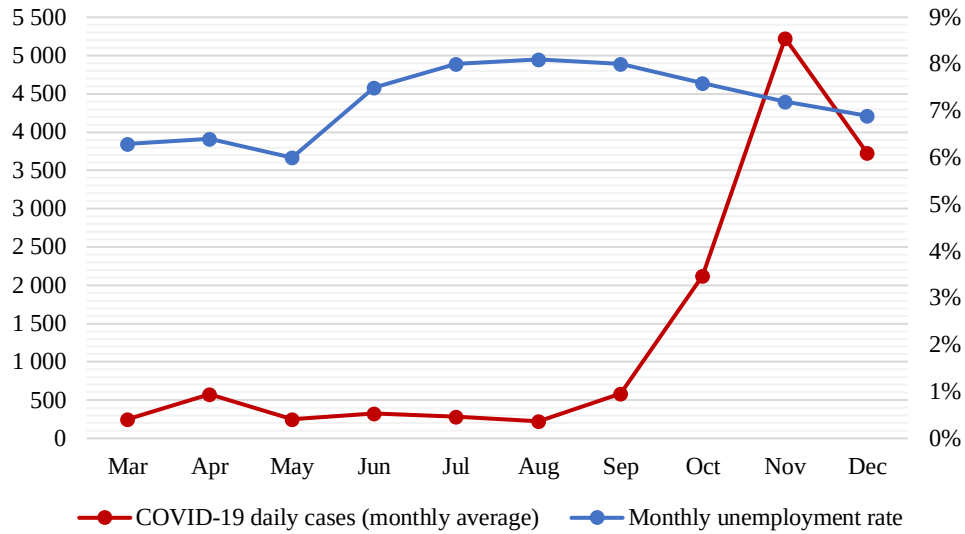


Figure 29 – Variation in the number of COVID-19 new daily cases per month (DGS, 2021) and in the monthly unemployment rate (INE, 2021) in Portugal throughout 2020

We took advantage of Apple and Google Mobility Reports to explore the mobility patterns throughout 2020. Figure 30 presents the changes in mobility trends of driving and walking provided by Apple (2021), while Figure 31 presents the changes regarding access to PT stations provided by Google (2020). Only Google (2020) provides data regarding Lisbon, all the remaining data is for the whole country. Furthermore, as the databases used different baselines, we cannot directly compare the changes in PT with changes in driving or walking. Nonetheless, we can observe that in both graphs the mobility demand falls sharply during each wave, recovering during the summer months. Still, while during summer driving and walking surpassed the baseline levels, PT ridership never fully reaches the pre-pandemic levels. Reports from PT operators in Lisbon provide additional evidence of the devastating impact of COVID-19 on PT, with the city's subway system registering a 51% ridership drop in 2020 comparatively to 2019 (Metropolitano de Lisboa, 2021).

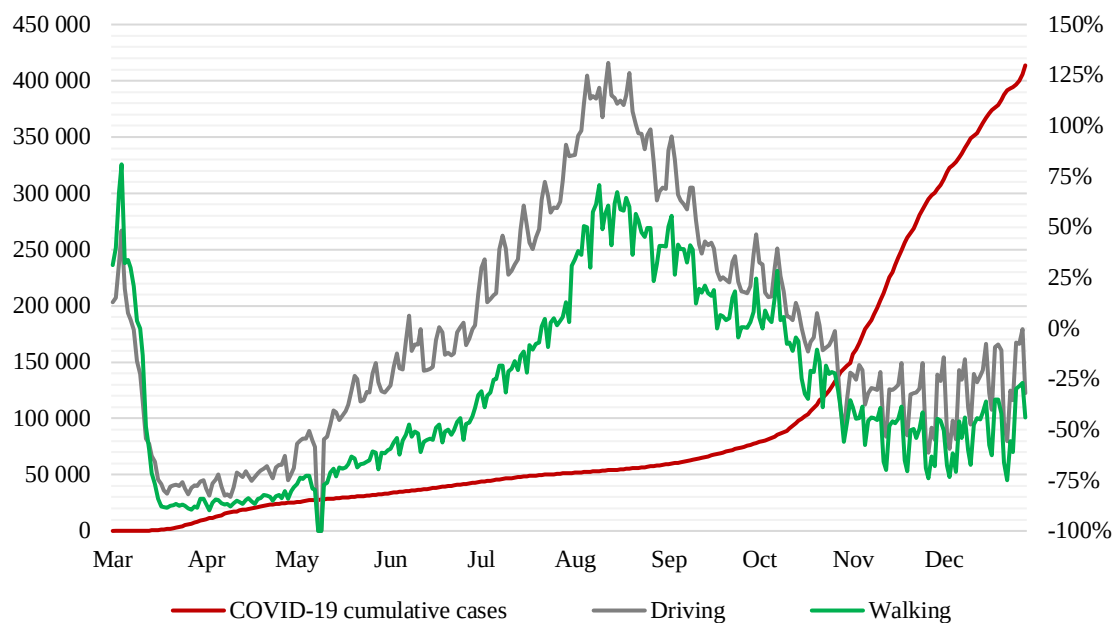


Figure 30 – Percentual changes in driving and walking mobility trends (comparatively to 13 January, 2020) (Apple, 2021) versus the increase in the number of COVID-19 cases (DGS, 2021) in Portugal throughout 2020

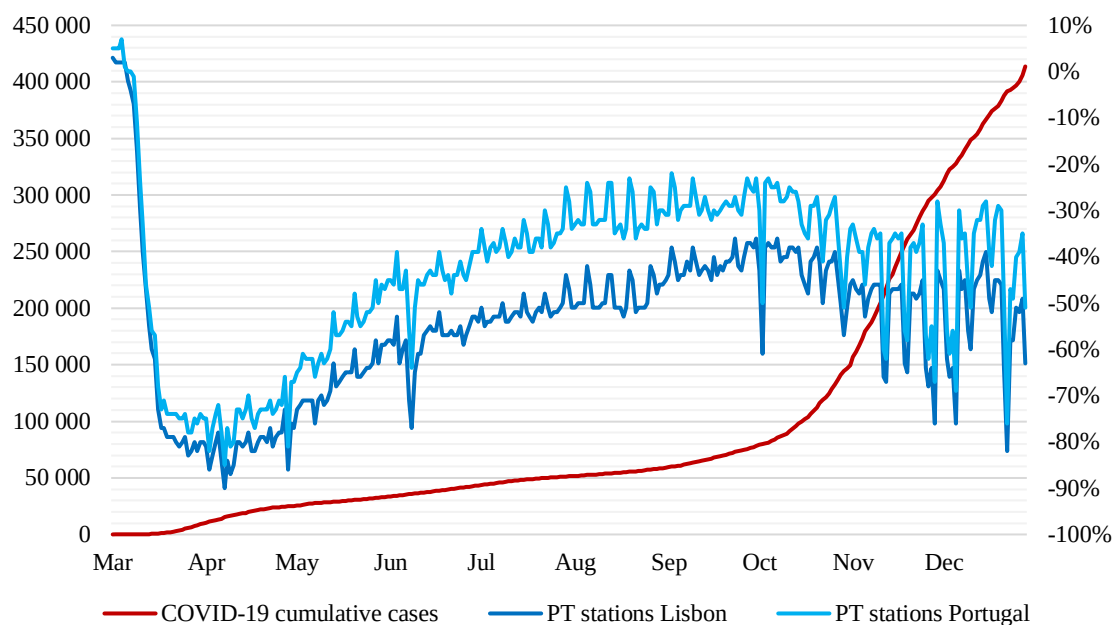


Figure 31 – Percentual changes in Lisbon's PT mobility trends (comparatively to a 5-week median baseline between January 3 and February 6, 2020) (Google, 2020) versus the increase in the number of COVID-19 cases (DGS, 2021) in Portugal throughout 2020

5.3.2. LISBON'S CYCLING STRATEGY AND BIKE SHARING SYSTEM

The promotion of cycling as a mode of transport has been gaining prominence in Lisbon in recent years. Since 2016, the municipality began the implementation of a 100 km dedicated cycling network, complemented by traffic calming measures and bike parking facilities (Câmara Municipal de Lisboa,

2020b). Concurrently, in 2017, the municipality implemented a public owned BSS, called *GIRA*, consisting of 700 shared bikes (2/3 e-bikes) and 83 stations. Figure 32 presents the implemented cycling network and the location of *GIRA*'s stations, with these interventions being mainly concentrated in the city centre and along the riverside.

Bike counts carried out before COVID-19 in strategic points of the city indicate encouraging signs of an increase in cycling use as the number of cyclists increased 817% between 2016 and 2018, with 34% of all observed cycling trips in 2018 being conducted by *GIRA*'s users (Félix, Cambra and Moura, 2020).

In response to the impacts of the COVID-19 pandemic, Lisbon announced the implementation of an additional 76.5 km of new pop-up cycling lanes (Figure 32 presents in red the pop-up lanes already operational at the time of this study), complemented by new bike parking facilities and the establishment of an initiative to subsidize the purchase and repairing of personal bicycles (Câmara Municipal de Lisboa, 2020a). Likewise, new expansions of *GIRA* were announced, including the deployment of new shared e-bikes. By 2030 the municipality plans to have a 200 km dedicated cycling network and to have *GIRA* covering the entire city (Câmara Municipal de Lisboa, 2020b). Bike counts conducted by the municipality in 2020 support this cycling strategy, as they registered a 25% increase in cycling use between 2019 and 2020 (Moura, Félix and Reis, 2020).

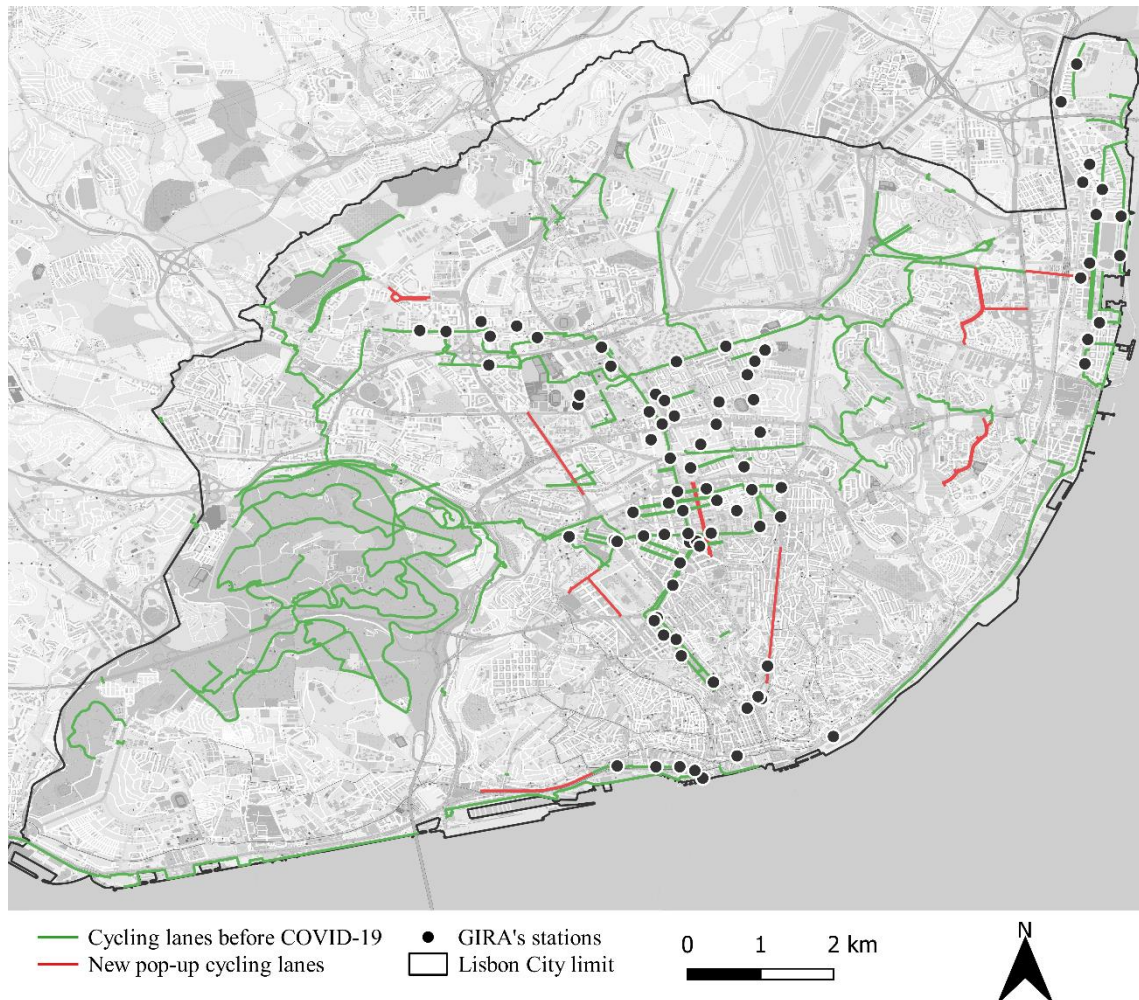


Figure 32 – Existing cycling infrastructure and location of *GIRA*'s stations within the city of Lisbon

5.4. METHODOLOGY

5.4.1. SURVEY DESIGN AND IMPLEMENTATION

A survey was designed and implemented aimed at assessing the main motivations for BSS use as well as the impacts of COVID-19 on those motivations. Respondents were asked to rate the importance of 19 motivations (Figure 33) on their decision to use *GIRA* using a Likert measurement scale ranging from 1 (*not important at all*) to 5 (*very important*). In addition to the several motivations identified in the literature as influencing BSS usage before COVID-19 (subsection 5.2.1.), we added the motivation of social distancing due to the characteristics of this pandemic. Standard socioeconomic and demographic as well as travel behaviour questions were also included.

In order to assess the coronavirus impact on the motivations for using bike sharing, we began by informing the respondents that throughout the survey we would ask them, in specific questions, to compare their current daily routines and behaviour (during COVID-19) with a time when the pandemic did not affect their lives (we suggested, comparing with the first two months of 2020). Next, we asked the respondents about their current relationship with *GIRA*:

- A. *Being a GIRA user before and during the COVID-19 pandemic*
- B. *Have joined GIRA during the COVID-19 pandemic*
- C. *Being a GIRA user before the COVID-19 pandemic, but have stopped using the system*

Respondents were asked to retrospectively rate their motivations for using *GIRA* before COVID-19 (groups A and C) and in the current situation (groups A and B). To the respondents who were *GIRA* users before COVID-19 and continue to use the system (group A) we requested them to compare the importance of each motivation before and during COVID-19. Consequently, we were able to categorize our respondents into two “distinct” periods of analysis:

- **Before COVID-19**, comprised by the combination of the retrospective questions asked to the respondents that continue to use the system (group A) and to the former users (group C)
- **During COVID-19**, constituted by the combination of the answers from the new users (group B) and the answers of the respondents that continue to use the system in relation to the current situation (group A)

Furthermore, the respondents who stopped using the system were asked to choose if their reason for quitting the system was a consequence of the COVID-19 or if it was because of other reasons not related to the pandemic. According to their answer, the respondents were requested to select, from a defined set of options, their reasons for quitting (multiple choice was allowed).

The survey was performed in an online-only format, being available between September and October, 2020. It was disseminated through social media (including in the official pages of parish councils, cyclists and bike sharing user groups as well as neighbourhood associations), local press and universities' mailing lists. The time needed to complete the survey was between 10 min to 15 min. A total of 442 respondents opened the survey and indicated to use or have used *GIRA*, of which 294 completed the survey.

5.4.2. STATISTICAL ANALYSIS

Descriptive statistics were utilized to analyse the socioeconomic and demographic profile of the respondents, their main mode of transport as well as for an initial examination of the motivations for BSS use.

We have employed exploratory factor analysis (EFA) with the objective of summarizing and reducing the motivations for using BSS into a smaller number of representative factors (Field, 2013b; Hair *et al.*, 2014). As the main purpose for the EFA was to reduce our original motivations into a smaller and more manageable number of latent factors, we have applied Principal Component Analysis (PCA) as the method for factor extraction⁷ (Field, 2013b; Hair *et al.*, 2014). The number of factors to extract was decided through the eigenvalue and scree plot criteria (Field, 2013b; Hair *et al.*, 2014). Variables with no significant correlations ($r < .3$), very high correlations ($r > .8$) or with significant cross-loadings were excluded (Field, 2013b). To achieve a simpler and more meaningful factor matrix, we applied the orthogonal rotation *VARIMAX*⁸. Lastly, we utilized the reliability coefficient *Cronbach's α* to assess the internal consistency of our factors (Hair *et al.*, 2014).

To determine the most important motivations for using bike sharing and to compare between the periods before and during COVID-19, we subjected the obtained factors from the EFA to a one-way repeated measures ANOVA. Repeated measures ANOVA is used when we want to compare more than two group means where the participants are the same in each group (Field, 2013e). In our case we aim to compare the importance of each factor resulting from the EFA among all factors and in each of the two distinct periods. As an additional validation of our results, we also conducted the Friedman test with pairwise Wilcoxon Signed Ranks post-hoc tests, which is the non-parametric equivalent to the one-way repeated measures ANOVA (Field, 2013d), and obtained the same results⁹. Similarly to other non-parametric tests, the Friedman test uses ranks to compare the data (Field, 2013d). Lastly, we employed independent-samples *t-tests* (Field, 2013a) to explore possible differences on the motivational factors between the respondents who have recently joined and those who were already users before the pandemic and continue to use the system. Like in the case of ANOVA, we also used the non-parametric equivalent of the independent-samples *t-test* to validate our results: the Mann-Whitney U test (Field, 2013d). The Friedman test with pairwise Wilcoxon Signed Ranks post-hoc tests as well as the Mann-Whitney U tests are presented in Appendix A7.1. The statistical analyses were all conducted on IBM SPSS Statistics, version 26 for Windows.

5.4.3. SAMPLE DESCRIPTION

A total of 294 respondents completed the survey. We start by analysing in Table 15 the representativeness of our sample by comparing it with a larger survey conducted by GIRA's operator between January and February 2019 (Moura and Félix, 2019).

⁷ We have also employed the alternative common factor analysis (specifically Principal Axis Factoring) and obtained the same factor matrix.

⁸ We tested the oblique rotation method *Oblimin* but as the obtained correlation matrix between the factors revealed no significant correlations ($r < .3$), we can assume our factors to be independent and, therefore, an orthogonal rotation is preferred (Field, 2013b).

⁹ When analysing Likert-scales (constituted by more than a single Likert item, like our case in which we are comparing factors) using parametric tests like ANOVA is typically accepted (Carifio and Perla, 2008; Norman, 2010).

Table 15 – Comparison of the general statistics between the samples of the 2020 and 2019 surveys

		2020 survey (N=294)	GIRA's operator 2019 survey (N=4970)
Place of residence	Lisbon City	86%	71%
Gender	Female	39%	33%
	Male	61%	67%
Age	< 18	1%	1%
	18-24	16%	14%
	25-34	28%	29%
	35-44	24%	30%
	45-54	25%	19%
	> 54	6%	7%
Education	Basic Education	0%	2%
	Secondary Education	13%	15%
	Higher Education	87%	83%
Employment status	Working	72% ^a	84% ^b
	Not working	4%	2%
	Retired	2%	2%
	Studying	21%	12%
With a GIRA annual subscription		94%	90%
With a driving's license		89%	N/A
With a PT monthly pass		46%	39%
Car available for use		78%	84%
Bicycle available for use		59%	51%

^a Does not include working students; ^b Includes working students

The average respondent in our sample lives in the city of Lisbon (86%), is male (61%), has a higher education degree (87%) and is employed (72%). The vast majority of respondents have an annual subscription of *GIRA* (94%). Moreover, having a driving's license (89%) and access to a car (78%) is more prevalent than having a PT monthly pass (46%) or a personal bicycle (59%).

Overall, our sample is similar to the results obtained by *GIRA*'s operator, albeit it presents a higher share of respondents living in the city of Lisbon. Furthermore, our sample has a higher share of students and a lower share of respondents working. This can be explained, on the one hand, by different methodological considerations (the survey from *GIRA*'s operator considered working students in the working category contrary to our survey) and, on the other hand, by a rise on unemployment resulting from the COVID-19 crisis (Figure 29). Likewise, our sample presents a higher share of users having a PT monthly pass. Two explanations are presented. Firstly, we asked the respondents if they have or usually have a PT monthly pass, not specifying a period which could have led to an underestimation of the COVID-19 effect. Secondly, on April 2019 (between the period of the two surveys) the Portuguese Government implemented a major nationwide restructuring of PT monthly passes, which led to significant savings and a steady increase in PT users up until the COVID-19 pandemic (IMT, 2020).

Next, we divided our sample in the three groups of users previously mentioned (former users, new users and respondents who were users before COVID-19 and continue to use the system), with their main demographic and socioeconomic characteristics represented in Table 16. Although the small number of respondents in each group, particularly regarding the group of new users, restricts possible generalizations, we can observe that the former users tend to have higher car (84% versus 79% of users before and during COVID-19 and 60% of new users) and bicycle availability (68% versus 58% of users before and during COVID-19 and 37% of new users). Furthermore, the majority of new users in our sample are women (60% versus 39% of users before and during COVID-19 and 32% of former users) and tend to be younger (74% are under 35 years old comparatively to only 40% of users before and during COVID-19 and 43% of former users).

According to our previous classification of the periods of analysis to be considered (subsection 5.4.1.), in the period before COVID-19 we obtained 259 valid answers (retrospective questions from groups A and C), while in the period during COVID-19 we have 195 valid answers (current answers from groups A and B).

Table 16 – Demographic and socioeconomic characteristics of the respondents profiled according with their current relationship with *GIRA* (no longer using, continue to use or joined recently)

		Former users (N=99)		Users before and during COVID-19 (N=160)		New users (N=35)	
		n	%	n	%	n	%
Place of residence	Lisbon City	76	77%	146	91%	31	89%
	Lisbon Metropolitan Area	23	23%	14	9%	4	11%
Gender	Female	32	32%	63	39%	21	60%
	Male	67	68%	97	61%	14	40%
Age	< 18	1	1%	1	1%	1	3%
	18-24	13	13%	22	14%	12	34%
	25-34	29	29%	40	25%	13	37%
	35-44	20	20%	44	28%	6	17%
	45-54	25	25%	46	29%	3	9%
	> 54	11	11%	7	4%	0	0%
Education	Basic Education	0	0%	0	0%	1	3%
	Secondary Education	9	9%	22	14%	7	20%
	Higher Education	90	91%	138	86%	27	77%
Employment status	Working	71	72%	121	76%	21	60%
	Not working	3	3%	8	5%	2	6%
	Retired	4	4%	1	1%	0	0%
	Studying	21	21%	30	19%	12	34%
With a <i>GIRA</i> annual subscription		90	91%	155	97%	30	86%
With a driving's license		93	94%	141	88%	27	77%
With a PT monthly pass		45	45%	68	43%	21	60%
Car available for use		83	84%	126	79%	21	60%
Bicycle available for use		67	68%	92	58%	13	37%

5.5. RESULTS

5.5.1. DESCRIPTIVE STATISTICS

5.5.1.1. MAIN MODE OF TRANSPORT

To better contextualize the motivations for using *GIRA* before and during COVID-19, we start our analysis by observing the main modes of transport used by our respondents in their commuting trips between the two periods (Table 17). The respondents could select one or multiple modes in their commute, with walking trips only considered if there were made exclusively or were longer than 5 consecutive minutes in a combined trip. Furthermore, respondents had the option to declare to no longer commute during COVID-19.

Table 17 – Modal share of the main modes of transport for commuting (trips from home to work or school) before (N=259) and during COVID-19 (N=171). Note: 24 of respondents that use *GIRA* in the current situation declared to no longer commute

Main mode of transport for commuting trips	Before	Now
<i>GIRA shared bicycle</i>	23.0%	28.3%
<i>Public Transport</i>	33.4%	23.6%
<i>Walking</i>	19.6%	22.8%
<i>Private car</i>	10.2%	11.9%
<i>Personal bicycle</i>	8.2%	7.7%
<i>Taxi or equivalent</i>	2.6%	3.2%
<i>Motorcycle</i>	1.7%	1.7%
<i>Other</i>	1.2%	0.7%

Although the modal share of most modes of transport remains fairly stable between the two periods, we can observe two significant differences: a decrease in the modal share of PT and an increase in the modal share of *GIRA*. While before the pandemic, PT was the most frequently chosen mode (33.4%) followed by *GIRA* (23.0%), now *GIRA* has surpassed PT (28.3% versus 23.6%) as the most used mode by our respondents.

5.5.1.2. MOTIVATIONS FOR USING GIRA

We now turn our attention to the motivations for using *GIRA* before and during COVID-19. Figure 33 shows the motivations for using *GIRA* between the two periods, ranked according to the respondents highest scores.

The motivation with the highest scores in both periods was the existence of *GIRA* stations near the respondents' destinations, closely followed by the availability of shared e-bikes as well as the pleasure of cycling. Environmental concerns, the existence of *GIRA* stations near the respondents' home, as well as the availability of cycling lanes serving the trip and the easiness of using the system were also considered important motivations for using *GIRA* in both time periods. The relative higher importance given to the existence of *GIRA* stations near the respondents' destinations comparatively to the stations near home may be explained by *GIRA* stations being predominantly located in the city centre near major business districts and universities, with a scarcity of stations near residential areas. On the opposite spectrum, marketing was the least influential motivation with only 12% and 13% of respondents considering it to be an important or very important reason for using *GIRA* in each period. Similarly, motivations related to the social environment, such as the influence of family/friends/colleagues or

seeing other people using the system had also some of the lowest scores. Using *GIRA* to access PT was likewise considered of little importance, being even less important during COVID-19.

The importance of most motivations remained stable between the periods before and during COVID-19, with the major exceptions being the motivations of maintaining a social distance during the trip and avoiding the use of PT, which are now much more relevant. While using *GIRA* to avoid PT was already important to some users before COVID-19 (with a score similar to the motivations of travel costs reductions as well as health concerns and fitness improvement), the percentage of users considering it an important or very important motivation is now close to the importance given to the motivations of greater trip flexibility and easiness of using the system. Likewise, the percentage of respondents considering that maintaining a social distance during the trip is an important or very important reason for using *GIRA* has skyrocketed, moving from being one of least important motivations to being almost as important as the motivation of reducing travel times.

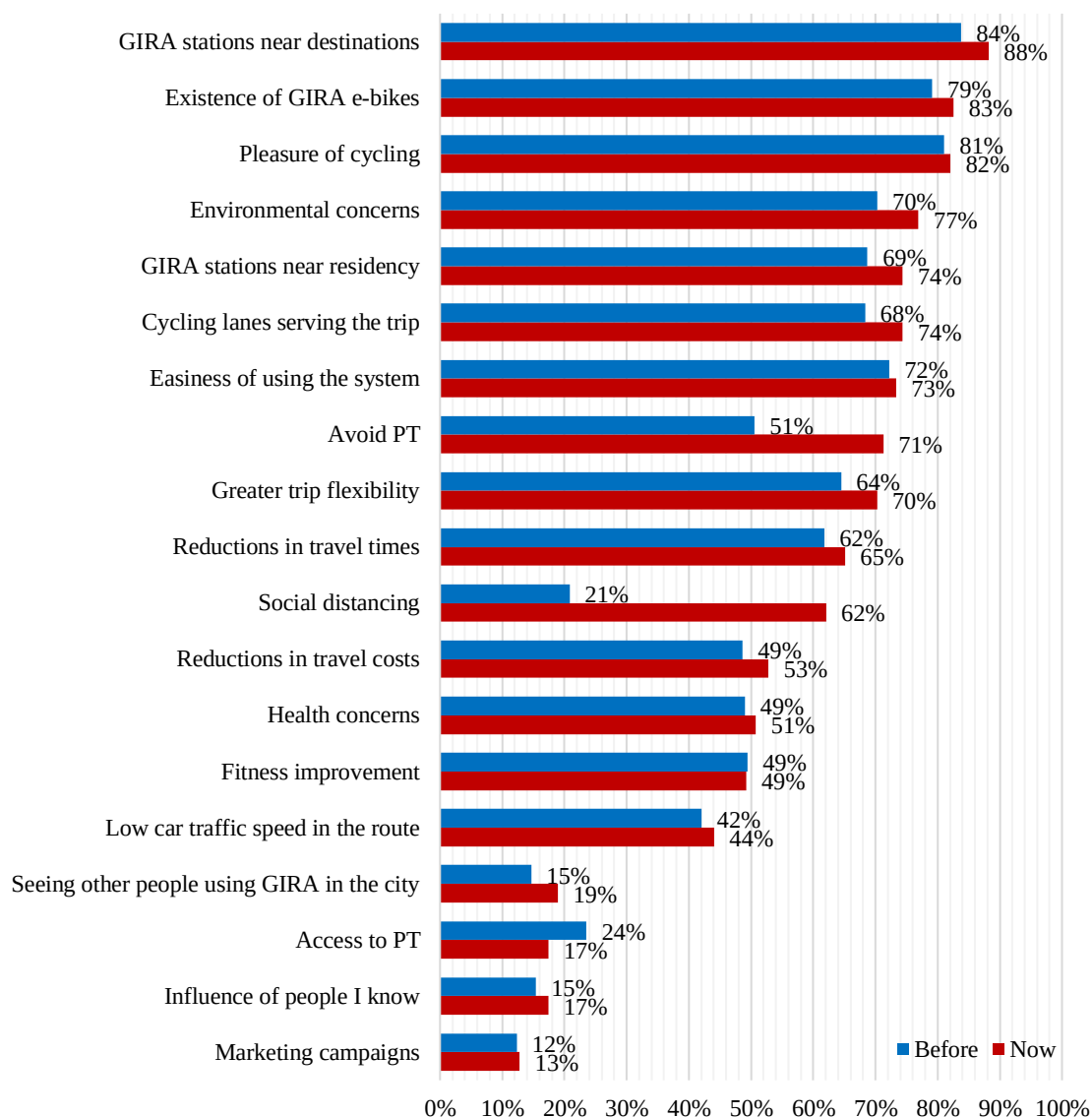


Figure 33 – Motivations for using *GIRA* ranked according to the respondents' importance assessment before (N=259) and during COVID-19 (N=195) (for easier reading only the combined percentage of the two highest ratings - *important* and *very important* - is displayed)

5.5.1.3. MOTIVATIONS OF NEW USERS VERSUS USERS BEFORE AND DURING COVID-19

We have also explored possible differences in the motivations between the users who have joined *GIRA* during the pandemic and the respondents who were already users before and continue to currently use *GIRA* (Figure 34). Although most motivations have the same importance for both user groups, the comparison reveals some substantial differences. Firstly, new users give considerably more importance to seeing other people using the system and to the influence of their social circle comparatively to the older users (a 15% and 14% difference, respectively). Likewise, marketing campaigns are more valued by new users (12% difference). More remarkably, the new users consider the motivations of health concerns and fitness improvement as much more important than the older users, with a difference of more than 30%, being to them as important as using *GIRA* to avoid PT.

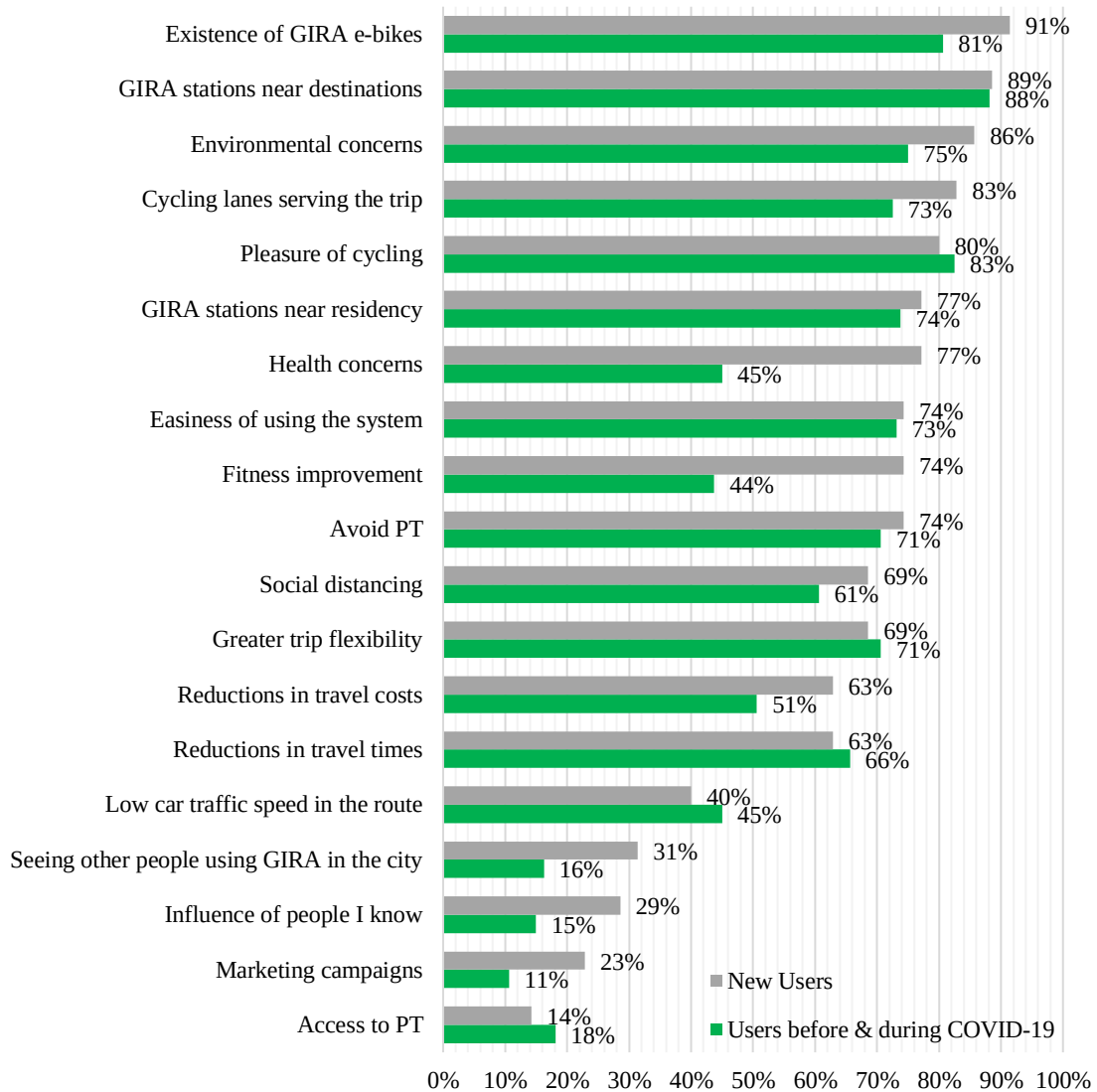


Figure 34 – Comparison of the motivations for using *GIRA* during COVID-19 between New Users (N=35) and Users Before and During COVID-19 (N=160) (for easier reading only the combined percentage of the two highest ratings - important and very important - is displayed)

5.5.1.4. REASONS FOR QUITTING GIRA

Lastly, we asked the respondents who have quitted *GIRA* to justify their choice. Of the 99 respondents who have quitted the system, only 30 justified their decision on the consequences of the pandemic, while 69 stopped using *GIRA* due to reasons not directly related to COVID-19. For the respondents who quitted *GIRA* due to the pandemic, most justified their decision on the trip purpose no longer existing (49%), with only a minority avoiding using the system due to infection fears (38%).

Regarding the users who quitted *GIRA* due to reasons not related to COVID-19, their answers are presented in Figure 35, with most of their chosen reasons being linked to the coverage and quality of the system. The shortage of shared bikes (26%), particularly e-bikes (20%), was the most chosen reason for quitting the system, followed by the lack of *GIRA* stations near their destinations or home (17%), poor condition of the bikes (11%) as well as a lack of available docking points to return the *GIRA* bicycles (10%). Changing home or work/study location (10%) and shifting to their personal bicycle (8%) were the most frequently chosen reasons not directly connected to the systems' coverage and quality.

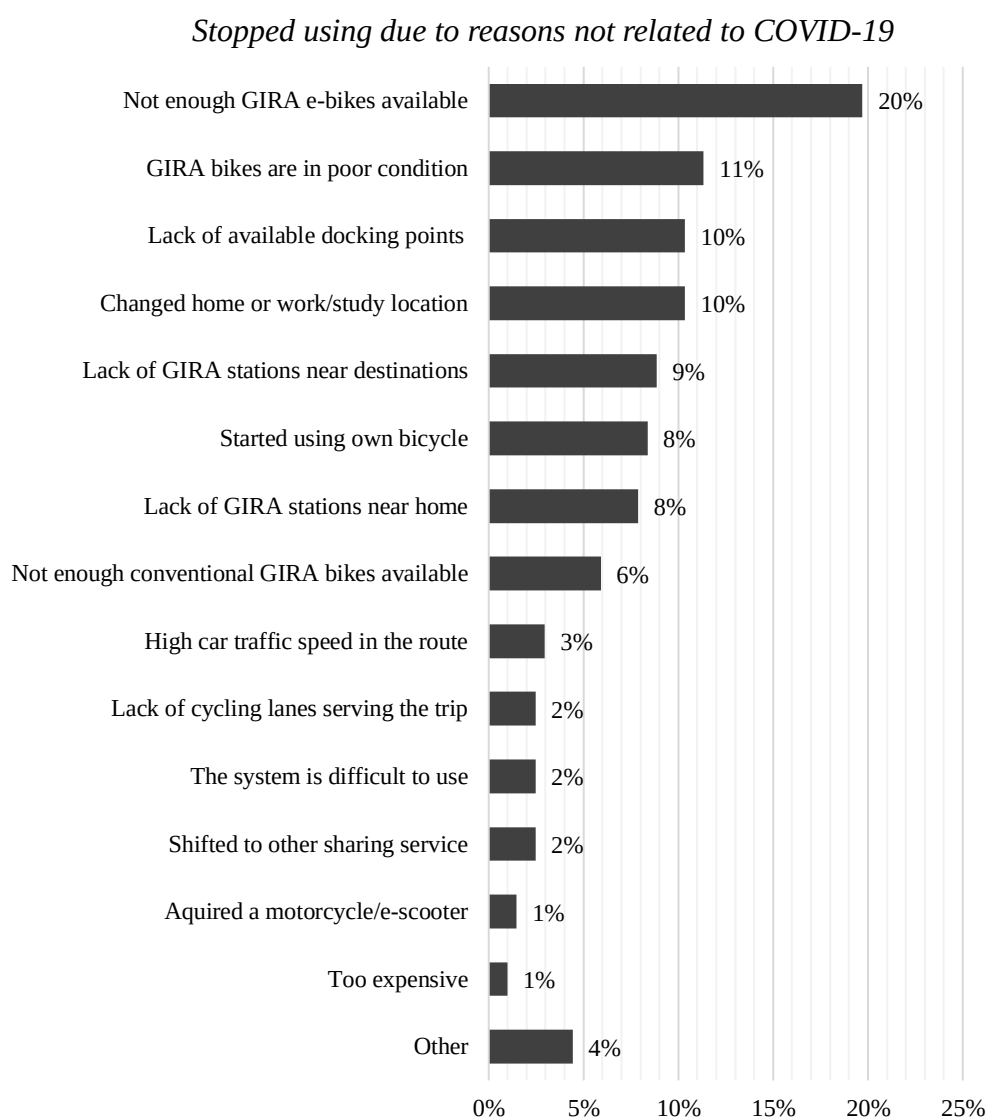


Figure 35 – Reasons for stopping using *GIRA* not related to the COVID-19 pandemic (N=69) (multiple choice) (responses to the question “Having replied that you stopped using *GIRA* for other reasons unrelated to the pandemic, what were the reasons for that decision?”)

5.5.2. ANALYSIS OF MOTIVATIONS BEFORE AND DURING COVID-19

5.5.2.1. FACTOR ANALYSIS

Factor analysis was conducted to aggregate the motivations presented in Figure 33 into a smaller and more manageable number of latent factors. We removed the motivation *access to PT* from the analysis due to a lack of meaningful correlations with the other variables (all correlations were below 0.3). Furthermore, as the variables *health concerns* and *fitness improvement* were highly correlated ($r > .8$), we decided to exclude the latter¹⁰ from the analysis to avoid multicollinearity issues (Hair *et al.*, 2014). Finally, the motivation *low car traffic speeds in the route* was also removed due to significant cross-loadings. Each time a variable was removed, the EFA was repeated. The three variables had the same problems in both samples and, therefore, were removed from both.

In the end, 16 different motivations were retained, obtaining the same 5 distinct factors in both time periods. Both samples had acceptable Kaiser-Meyer-Olkin (KMO) Measures of Sampling Adequacy (KMO=0.77 before COVID-19 and KMO=0.68 during COVID-19), and all KMO values for the individual items were 0.6 or greater (well above the 0.5 minimum threshold) (Field, 2013b). Likewise, the Bartlett's Test of Sphericity was significant ($p < .001$) in the two samples. Table 18 and Table 19 represent, respectively, the factor analyses conducted in the periods before and during COVID-19. Cross-loadings lower than 0.4 were omitted from the tables for easier reading.

¹⁰ We also conducted the analysis removing *health concerns* instead and obtained the same result. Ultimately, we opted for excluding *fitness improvement* due to a lower *Cronbach's alpha* score obtained in the corresponding factor.

Table 18 – EFA before COVID-19 (Total variance explained= 60.4%, N=259)

	Service Coverage & Quality	Social Influence	Utility & Competitiveness	Personal Interests & Well-being	Social Discomfort
<i>GIRA stations near home</i>	0.735				
<i>GIRA stations near destinations</i>	0.735				
<i>Existence of GIRA e-bikes</i>	0.728				
<i>Cycling lanes serving the trip</i>	0.584				
<i>Easiness of using the system</i>	0.539				
<i>Seeing other people using GIRA in the city</i>		0.812			
<i>Influence of people I know</i>		0.745			
<i>Marketing campaigns</i>		0.700			
<i>Reductions in travel times</i>			0.771		
<i>Greater trip flexibility</i>			0.757		
<i>Reductions in travel costs</i>			0.692		
<i>Health concerns</i>				0.792	
<i>Pleasure of cycling</i>				0.756	
<i>Environmental concerns</i>				0.653	
<i>Avoid PT</i>					0.769
<i>Social distancing</i>		0.467			0.616
Eigenvalues	3.84	1.98	1.47	1.39	0.99
% of variance explained	14.9%	12.9%	12.2%	12.1%	8.5%
Cronbach's Alpha (α)	0.71	0.68	0.68	0.68	0.55

Table 19 – EFA during COVID-19 (Total variance explained= 57.3%, N=195)

	Service Coverage & Quality	Utility & Competitiveness	Personal Interests & Well-being	Social Influence	Social Discomfort
<i>GIRA stations near home</i>	0.752				
<i>Existence of GIRA e-bikes</i>	0.740				
<i>GIRA stations near destinations</i>	0.626				
<i>Easiness of using the system</i>	0.492				
<i>Cycling lanes serving the trip</i>	0.395				
<i>Reductions in travel times</i>		0.710			
<i>Greater trip flexibility</i>		0.651			
<i>Reductions in travel costs</i>		0.596			
<i>Health concerns</i>			0.778		
<i>Pleasure of cycling</i>			0.726		
<i>Environmental concerns</i>			0.678		
<i>Seeing other people using GIRA in the city</i>				0.806	
<i>Influence of people I know</i>				0.725	
<i>Marketing campaigns</i>				0.654	
<i>Social distancing</i>					0.850
<i>Avoid PT</i>					0.740
Eigenvalues	3.35	1.76	1.50	1.36	1.20
% of variance explained	12.6%	12.0%	11.4%	11.3%	10.0%
Cronbach's Alpha (α)	0.62	0.60	0.65	0.63	0.70

The motivations for using BSS can be represented by five distinct factors, with 60.4%, and 57.3% of the total variance explained, respectively, before and during COVID-19:

- *Service Coverage & Quality* – characterized by the convenient location of BSS stations, the easiness of using the system, as well as amenities valued by users like the availability of shared e-bikes and the existence of cycling lanes serving their routes
- *Personal Interests & Well-being* – defined by the perceived environmental and health benefits of using bike sharing, as well as the pleasure and enjoyment of cycling
- *Utility & Competitiveness* – represented by the transport advantages of bike sharing, such as reductions in travel times and costs as well as the flexibility provided by shared bikes
- *Social Influence* – constituted by the influence of the social circles as well as the perceived social acceptance of using bike sharing in the city
- *Social Discomfort* – constituted by the motivations more affected by COVID-19, specifically using *GIRA* to maintain a social distance during the trip and as an alternative to PT

Cronbach's α presented accepted values for an exploratory study (Hair *et al.*, 2014) in all factors except on *Social Discomfort* in the period before COVID-19 (below the minimum threshold of 0.60), however in the current period the *Cronbach's α* of this factor has substantially increased to 0.70. The low *Cronbach's α* score can be attributed to the motivation of maintaining a social distance, which also presents a significant cross-loading with the factor *Social Influence* in the period before COVID-19. Such problems can be explained by the nature of this motivation, which before COVID-19 had a different context, more associated with avoiding interacting with other people or with the discomfort of being in crowded places that, for instance, characterize PT (Thomas, 2009; Haywood, Koning and Monchambert, 2017). During COVID-19, maintaining a social distance has gained a new meaning, and much more relevance, as it is now connected to the fear of infection.

5.5.2.2. REPEATED MEASURES ANOVA

The resulting five factors from the previous factorial analyses were submitted to a one-way repeated measures ANOVA¹¹ to determine the importance of each factor. The procedure was conducted separately for each time period (i.e., before COVID-19 and now). As Mauchly's test indicated that the assumption of sphericity was violated in both samples (χ^2 (9)=41.12; $p<.001$ for the sample before COVID-19 and χ^2 (9)=53.00; $p<.001$ for the sample during COVID-19), we considered the corrections when this assumption is violated (Field, 2013e), which are provided in Appendix A7.2.

As the repeated measures ANOVA was statistically significant (even when considering the corrections for the violation of sphericity), we can accept that there are significant differences between the factors and analyse the post-hoc estimated marginal means and pairwise comparisons. The estimated mean scores as well as the pairwise comparisons of each factor in the period before COVID-19 are, respectively, represented in Table 20 and Table 22, while the corresponding results for the period during COVID-19 are displayed in Table 21 and Table 23.

¹¹ Before conducting the repeated measures ANOVA, possible outliers of the summated scales derived from the EFA (and calculated through simple means) were detected and removed based on z-scores > 3.29 (Field, 2013f), resulting in one outlier being removed from the sample before COVID-19 and two outliers being removed from the sample during COVID-19.

Table 20 – Estimated marginal means of the motivations for using *GIRA* before COVID-19 (N=258)

Motivations	Mean	Std. Deviation	Std. Error	95% CI
<i>Service Coverage & Quality</i>	4.035	0.789	0.049	[3.938; 4.132]
<i>Personal Interests & Well-being</i>	3.882	0.902	0.056	[3.772; 3.993]
<i>Utility & Competitiveness</i>	3.602	1.019	0.063	[3.477; 3.727]
<i>Social Influence</i>	2.059	0.953	0.059	[1.943; 2.176]
<i>Social Discomfort</i>	2.738	1.220	0.076	[2.589; 2.888]

Table 21 – Estimated marginal means of the motivations for using *GIRA* during COVID-19 (N=193)

Motivations	Mean	Std. Deviation	Std. Error	95% CI
<i>Service Coverage & Quality</i>	4.152	0.703	0.051	[4.053; 4.252]
<i>Personal Interests & Well-being</i>	3.969	0.865	0.062	[3.846; 4.092]
<i>Utility & Competitiveness</i>	3.689	0.960	0.069	[3.553; 3.825]
<i>Social Influence</i>	2.085	0.950	0.068	[1.950; 2.219]
<i>Social Discomfort</i>	3.785	1.320	0.095	[3.598; 3.972]

Table 22 – Pairwise comparisons of the motivations for using GIRA before COVID-19 (N=258)

	Motivations	Mean Difference	Std. Error	95% CI for Difference ^b
<i>Service Coverage & Quality</i>	Personal Interests & Well-being	0.152	0.065	[-0.031; 0.336]
	Utility & Competitiveness	0.433 ^{*b}	0.067	[0.242; 0.624]
	Social Influence	1.975 ^{*b}	0.070	[1.776; 2.175]
	Social Discomfort	1.297 ^{*b}	0.084	[1.058; 1.535]
<i>Personal Interests & Well-being</i>	Service Coverage & Quality	-0.152	0.065	[-0.336; 0.031]
	Utility & Competitiveness	0.280 ^{*b}	0.072	[0.077; 0.484]
	Social Influence	1.823 ^{*b}	0.072	[1.620; 2.026]
	Social Discomfort	1.144 ^{*b}	0.077	[0.927; 1.361]
<i>Utility & Competitiveness</i>	Service Coverage & Quality	-0.433 ^{*b}	0.067	[-0.624; -0.242]
	Personal Interests & Well-being	-0.280 ^{*b}	0.072	[-0.484; -0.077]
	Social Influence	1.543 ^{*b}	0.077	[1.324; 1.761]
	Social Discomfort	0.864 ^{*b}	0.086	[0.620; 1.107]
<i>Social Influence</i>	Service Coverage & Quality	-1.975 ^{*b}	0.070	[-2.175; -1.776]
	Personal Interests & Well-being	-1.823 ^{*b}	0.072	[-2.026; -1.620]
	Utility & Competitiveness	-1.543 ^{*b}	0.077	[-1.761; -1.324]
	Social Discomfort	-0.679 ^{*b}	0.075	[-0.891; -0.467]
<i>Social Discomfort</i>	Service Coverage & Quality	-1.297 ^{*b}	0.084	[-1.535; -1.058]
	Personal Interests & Well-being	-1.144 ^{*b}	0.077	[-1.361; -0.927]
	Utility & Competitiveness	-0.864 ^{*b}	0.086	[-1.107; -0.620]
	Social Influence	0.679 ^{*b}	0.075	[0.467; 0.891]

*The mean difference is significant at the 0.05 level

^bAdjustment for multiple comparisons: Bonferroni

Table 23 – Pairwise comparisons of the motivations for using GIRA during COVID-19 (N=193)

	Motivations	Mean Difference	Std. Error	95% CI for Difference ^b
<i>Service Coverage & Quality</i>	Personal Interests & Well-being	0.183	0.074	[-0.025; 0.392]
	Utility & Competitiveness	0.463 ^{*b}	0.075	[0.250; 0.676]
	Social Influence	2.068 ^{*b}	0.077	[1.850; 2.285]
	Social Discomfort	0.367 ^{*b}	0.101	[0.081; 0.653]
<i>Personal Interests & Well-being</i>	Service Coverage & Quality	-0.183	0.074	[-0.392; 0.025]
	Utility & Competitiveness	0.280 ^{*b}	0.079	[0.055; 0.505]
	Social Influence	1.884 ^{*b}	0.079	[1.659; 2.110]
	Social Discomfort	0.184	0.104	[-0.111; 0.479]
<i>Utility & Competitiveness</i>	Service Coverage & Quality	-0.463 ^{*b}	0.075	[-0.676; -0.250]
	Personal Interests & Well-being	-0.280 ^{*b}	0.079	[-0.505; -0.055]
	Social Influence	1.604 ^{*b}	0.086	[1.361; 1.848]
	Social Discomfort	-0.096	0.100	[-0.381; 0.189]
<i>Social Influence</i>	Service Coverage & Quality	-2.068 ^{*b}	0.077	[-2.285; -1.850]
	Personal Interests & Well-being	-1.884 ^{*b}	0.079	[-2.110; -1.659]
	Utility & Competitiveness	-1.604 ^{*b}	0.086	[-1.848; -1.361]
	Social Discomfort	-1.700 ^{*b}	0.104	[-1.996; -1.404]
<i>Social Discomfort</i>	Service Coverage & Quality	-0.367 ^{*b}	0.101	[-0.653; -0.081]
	Personal Interests & Well-being	-0.184	0.104	[-0.479; 0.111]
	Utility & Competitiveness	0.096	0.100	[-0.189; 0.381]
	Social Influence	1.700 ^{*b}	0.104	[1.404; 1.996]

*The mean difference is significant at the 0.05 level

^bAdjustment for multiple comparisons: Bonferroni

The pairwise comparisons revealed that before the pandemic the motivations more influential on the decision to use bike sharing were those related to the *Service Coverage & Quality* as well as to the users' *Personal Interests & Well-being*, followed by the motivations connected to *Utility & Competitiveness*. Conversely, the least influential motivations when comparing with each of the other motivational factors were linked to *Social Influence*.

During COVID-19 the relationship between most motivations remains the same, except for the motivations connected to *Social Discomfort*. While before COVID-19, *Social Discomfort* was the second least important motivation (only more significant than *Social Influence*), during the pandemic the prominence of *Social Discomfort* has increased substantially, being now as important as the motivations related to *Personal Interests & Well-being* and *Utility & Competitiveness* (the mean differences are no longer statistically significant). Only the motivations connected to the *Service Coverage & Quality* remain more important than *Social Discomfort* (statistically significant), but the mean difference is now much less pronounced.

5.5.2.3. INDEPENDENT SAMPLES T-TEST

Lastly, we employed *t-tests*¹² to analyse possible differences on the importance of the motivational factors between the users who have joined *GIRA* during COVID-19 and the respondents who were users before and during COVID-19 (Table 24). The importance of each motivational factor is mostly the same for both user groups during the pandemic. The only exception is the *Social Influence* factor, with new users considering the motivations linked to this factor to be statistically more important than the older users.

Table 24 – Comparison of the motivations for using *GIRA* between the New Users (N=35) and Users Before and During COVID-19 (N=158), as well as the *t-tests* (two-tailed) results and associated significance

Motivations	User type	Mean	Std. Deviation	Std. Error	<i>t-test</i>	Differences significant at $p < .05$ (test)
<i>Service Coverage & Quality</i>	New users	4.240	0.542	0.092	0.815	No
	Users before and during COVID-19	4.133	0.734	0.058		
<i>Personal Interests & Well-being</i>	New users	4.190	0.789	0.133	1.683	No
	Users before and during COVID-19	3.920	0.875	0.070		
<i>Utility & Competitiveness</i>	New users	3.743	0.754	0.128	0.436 ^b	No
	Users before and during COVID-19	3.677	1.002	0.080		
<i>Social Influence</i>	New users	2.410	1.039	0.176	2.261	Yes
	Users before and during COVID-19	2.013	0.917	0.073		
<i>Social Discomfort</i>	New users	3.971	1.124	0.190	1.042 ^b	No
	Users before and during COVID-19	3.744	1.359	0.108		

^bEqual variances not assumed

¹² Before conducting the *t-tests*, possible outliers of the summated scales derived from the EFA were detected and removed based on z-scores > 3.29 (Field, 2013f), resulting in two outliers being removed from the sample during COVID-19.

5.6. DISCUSSION, LIMITATIONS AND CONCLUSIONS

The analysis has revealed that the most influential motivations regarding BSS usage, overall, are those related to the *Service Coverage & Quality*, particularly the proximity of BSS stations to the users' destinations and the availability of shared e-bikes. The suitable location of BSS stations as a major motivation is in line with previous findings (Fishman *et al.*, 2014), and were an expected outcome as they greatly determine the ability to reach their desirable destinations. The existence of shared e-bikes revealed to be highly regarded by users. The availability of e-bikes can be a potential trigger for inducing cycling as it helps to overcome some of the main perceived barriers for bicycle use, such as physical effort and long trip distances (Félix, Moura and Clifton, 2019). However, the current price of buying an e-bike is still a barrier particularly for lower income groups. In that sense, the provision of shared bikes at an affordable usage cost could encourage new users to take up bike sharing.

The motivations connected to *Personal Interests & Well-being* were also deemed highly influential on the decision to use bike sharing. Moreover, the pleasure of cycling was found to have a similar level of importance as the motivations with the highest scores from *Service Coverage & Quality*. Notably, the importance given to these motivations also illustrates how BSS can help to minimize some of the negative effects on general well-being caused by the coronavirus pandemic (De Vos, 2020), through providing its users with an activity associated with positive emotions as well as a mean for performing physical activity when most of the usual exercise facilities are not available.

Inversely, the influence of the social environment on BSS usage was mostly disregarded by its users. The marketing campaigns in particular had amongst the lowest scores. Nevertheless, the *Social Influence* factor was found to be more valued by the new users who have joined *GIRA* during COVID-19. This could indicate that the coronavirus has led to an increase in the social acceptability of cycling, as evidenced by the significant rise on cycling levels during the pandemic in several countries (Buehler and Pucher, 2021), inducing new users to take up bike sharing. Likewise, the observed increase in the marketing campaigns' importance among new users may be related to the *GIRA's* current communication campaigns focused on the safety measures implemented to decrease the infection risk of using the system.

Finally, the impact of coronavirus on the motivations for using BSS is clearly represented by the rise on the importance of the motivational factor *Social Discomfort*. Before the pandemic, this factor was amongst the least prominent, only more important than *Social Influence*, being mostly represented by the motivation of using *GIRA* to avoid PT. Avoiding using PT was already a fairly important motivation prior to the pandemic and was related to the fact that Lisbon's PT network was facing a quality decline, namely by suffering from overcrowded services. With the emergence of COVID-19, *Social Discomfort* has gained a new relevance and meaning, becoming as important as the motivational factors of *Personal Interests & Well-being* and *Utility & Competitiveness*. If before the pandemic, there were already some respondents that considered *GIRA* as an attractive alternative to PT, now that number has drastically increase. Likewise, there is now a significant percentage of respondents that consider the maintenance of a social distance during the trip an important motivation for using *GIRA*, with this motivation acquiring a new significance connected to the fear of infection.

With the emergence of the coronavirus pandemic, BSS have gained a new role as a significant portion of their users now consider using bike sharing to avoid PT and to maintain a social distance in their trips as import or very important motivations. Therefore, BSS could increase the resilience of urban transport systems by potentially providing an alternative mode to PT, where physical distancing can be kept. Systems that provide e-bikes (found to be amongst the most valued motivations by users) could be especially capable of acting as an alternative to PT due to the increased range of e-bikes. As countries

prepare (again) to gradually reopen and ease travel restrictions, policymakers should consider BSS in their reopening strategies, taking advantage of the bike sharing's capability to act as an alternative to PT namely by deploying additional BSS stations near major trip generators to reduce the pressure from PT services. Likewise, policymakers could also explore possible synergies between bike sharing and *open streets* experiments or other similar initiatives (Glaser and Krizek, 2021), as BSS have the potential to reinforce the human scale of cities and counteract the lack of liveliness in the public space (while keeping a safe distance from others) exacerbated by the present pandemic.

Additionally, the identification of the motivators for bike sharing usage provides some insights on how BSS operators may tailor their promotional efforts. First, the implementation of new BSS stations or the deployment of shared e-bikes (and the associated advantages of e-bikes) should be widely publicised. Equally, marketing campaigns should focus on advertising the pleasure of cycling or the associated environmental and health benefits, as all these motivations were highly regarded by BSS users both before and during COVID-19. During disruptive public health pandemics such as the coronavirus, the usual marketing strategies could be complemented by promoting bike sharing as a mode of transport where a safe social distance can be maintained during the trip.

However, strategies promoting BSS need to be accompanied by measures aimed at increasing the safety of using bike sharing, which now encompasses two different dimensions. Firstly, traffic safety, where the risk posed by motor traffic needs to be minimized through the construction of segregated cycling lanes or the implementation of traffic calming measures within the catchment areas of BSS stations. Secondly, the risk of infection posed by coronavirus (and similar infectious respiratory diseases), where the transmission risk from contaminated surfaces or from gatherings near the BSS stations should be reduced through enhancing cleaning procedures and restricting contact between users (e.g., enforcing social distancing at the BSS stations or installing a larger number of smaller BSS stations covering the same area instead of a few high-capacity stations).

This study has some limitations. First, we resorted to a convenience sampling method, which can lead to an overrepresentation of respondents more easily accessible and more willing to participate. We have addressed this shortcoming by disseminating the survey in several online channels, obtaining a sample similar to the representative survey conducted by the system's operator. Furthermore, the comparison between the periods before and during COVID-19 relied on retrospective questions, which are susceptible to recall biases. However, the severity and disruptive nature of COVID-19, makes it realistic to assume that people still remember their behaviour before the pandemic.

Future studies could build upon and improve this research by performing similar assessments in additional BSS to validate these results. Follow-up research could further explore the behaviour and attitudes of respondents who have decided to join bike sharing during the pandemic. This can be achieved by collecting bigger samples of such users in similar surveys or through qualitative research designs such as semi-structured interviews. Comparing the perceptions and behaviour of users with non-users might also deliver valuable additional insights. The potential preference for bike sharing instead of PT could be further investigated through actual data on the modal shift dynamics between the two modes, replicating the methodologies of studies conducted prior to the coronavirus pandemic. It would be especially useful to perform longitudinal studies at different points of the pandemic (e.g., comparing the behaviour of BSS users during the lockdowns versus during the different reopening phases) to have a better understanding of possible structural changes that the coronavirus may induce on BSS usage and on its relationship with the broad transport system.

6.

FACTORS INFLUENCING MODAL SHIFT TO BIKE SHARING: EVIDENCE FROM A TRAVEL SURVEY CONDUCTED DURING COVID-19

This chapter presents an integral reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (n.d.) ‘Factors influencing modal shift to bike sharing: Evidence from a travel survey conducted during COVID-19’, Journal of Transport Geography (Under Review).”

ABSTRACT

With public transport (PT) systems currently heavily affected by the coronavirus pandemic, bike sharing systems (BSS) have gained a new importance as a substitute to car use in urban areas. A possible path to increase the BSS capability of replacing car trips is to understand why some car drivers are currently shifting to bike sharing. Consequently, this study analysed possible differences on the main reasons for using bike sharing between users replacing car trips and users replacing other modes of transport. To accomplish this, a travel behaviour survey was implemented to the users of Lisbon's BSS during the coronavirus pandemic. Among the main findings, users replacing car trips were more sensitive to travel cost reductions, while travel time reductions and the availability of e-bikes were more important to users shifting from PT or walking. Moreover, users replacing car trips and using BSS as a first/last mile connector to PT were less affected by the pandemic than similar users replacing PT or walking trips. Additionally, the main reasons for users to choose BSS instead of a personal bicycle were theft concerns followed by considering BSS to be more convenient. Findings suggest that policies focused on cost savings may be particularly relevant to induce further car modal shift to BSS.

KEYWORDS: Bike sharing; Car reduction; Modal shift; Motivations; Coronavirus

6.1. INTRODUCTION

The sector with the fastest growing rates of CO₂ emissions (the main contributor to climate change) is the transport sector with emissions increasing at a rate of 2.5% per year (Rogelj *et al.*, 2018). At the same time is the least diversified energy end-use sector with 92% of transport energy demand consisting of oil products (Rogelj *et al.*, 2018). The transport sector is already responsible for 23% of global energy-related CO₂ emissions, of which almost three-quarters are generated by road transport with car travel being the main source (Graham-Rowe *et al.*, 2011).

As a response to this and to the several other negative externalities associated with private car usage (Douglas *et al.*, 2011; Gössling, 2020), policymakers around the world are introducing measures aimed at reducing car use (Ogilvie *et al.*, 2004; Graham-Rowe *et al.*, 2011). Among those policies, cycling has started to gain attention as a possible solution to tackle car dependence, especially in urban areas (Pucher and Buehler, 2008). Inducing a modal shift from private car to cycling could play a prominent role in the decarbonization of urban transport systems, being amongst the most efficient ways of reducing mobility-related CO₂ emissions (Brand, Dons, *et al.*, 2021; Brand, Götschi, *et al.*, 2021). For instance, a recent comprehensive study quantifying the life cycle CO₂ emissions from different modes of transport in seven European cities found emissions decreasing by 14% for each additional cycling trip and by 62% for each avoided car trip, leading to an average reduction of 3.2 kg of CO₂/day per each person shifting from car to cycling (Brand, Dons, *et al.*, 2021).

The promotion of cycling as an alternative mode of transport gains a heightened importance in the current COVID-19 pandemic. Infection fears and risks have particularly affected public transport systems, leading to ridership drops never witnessed before (Gkiotsalitis and Cats, 2020; Teixeira and Lopes, 2020), while the use of private car has been much less affected (Sharifi and Khavarian-Garmsir, 2020). Thus, the current over reliance on car travel could be further exacerbated by the COVID-19 pandemic due to a potential loss of confidence on the use of public transport (PT) and a modal shift from PT users to the private car.

Due to its flexibility and competitiveness in travel times, combined with a low risk of infection, the bicycle has been positioning itself during the COVID-19 pandemic as an alternative to both PT and the car, increasing the resilience of urban transport systems (Teixeira and Lopes, 2020; Teixeira, Silva and Moura e Sá, 2022a, 2022b). One of the most popular policies promoting cycling is the implementation of bike sharing systems (BSS), with more than 2000 systems already in operation across the world (DeMaio and Meddin, 2020). Characterized by their high technology incorporation and continuous development¹³, BSS are particularly suited for increasing both the number (by providing access to utility bicycles at an affordable cost) and the diversity of cyclists, contributing to the normalization of cycling as a mode of transport (Goodman, Green and Woodcock, 2014; Teixeira, Silva and Moura e Sá, 2021a). Furthermore, available research has already established that bike sharing can replace car trips (Basu and Ferreira, 2021; Teixeira, Silva and Moura e Sá, 2021a), however the ability of inducing car modal shift differ substantially between systems and the factors leading to these different outcomes are not yet fully understood (Teixeira, Silva and Moura e Sá, 2021a).

Consequently, it is fundamental to understand the ability of bike sharing of attracting car users to better comprehend the potential role of BSS towards the decarbonization of urban transport systems. Understanding the reasons behind the decision of some car users to choose bike sharing could provide valuable information on how to enhance the competitiveness of BSS against the car, opening a possible path for increasing their ability of replacing car trips. Thus, the objective of this study is to explore

¹³ Since the appearance of the 3rd generation systems in the 2000s that led to their rise, BSS have continued to innovate, first with the surge of the *dockless* systems and now with the incorporation of e-bikes.

possible differences on the main reasons for using bike sharing between users replacing car trips and users replacing other modes of transport, specifically PT and walking. The identification of the significant motivations associated with the different modes of transport being replaced could lead to a better understanding of the mode substitution capability of bike sharing, potentially providing key evidence to policymakers and operators on how to tailor and optimize BSS to induce further car use reductions. Furthermore, the scale of disruption provoked by the coronavirus pandemic could have led to changes on the attitudes and behaviour towards mobility, inducing new modal shift dynamics. Accordingly, and through a survey conducted to the users of *GIRA* (Lisbon's BSS), this study aims at providing evidence to the following research question:

- *How do the motivations for using BSS differ across users replacing different modes of transport before and during COVID-19?*

By identifying the major factors explaining the modal shift dynamics to bike sharing before and during COVID-19, this research aims at providing evidence on how to optimize BSS to induce further shifts from private motorized modes of transport (especially the car), subsequently, improving the contribution of BSS towards a more sustainable transport system.

The rest of the paper is organized in five sections. An overview of the main modal shift dynamics induced by bike sharing and the factors explaining the attractiveness of BSS to some segments of the population is presented next (section 6.2.). This is followed by the presentation of the methodology (section 6.3.), including the main research assumptions and modelling approach, as well as a brief description of the case-study. Next, the analysis of the differences on the reasons for using BSS between users replacing different modes before and during COVID-19 is revealed (section 6.4.), followed by its discussion (section 6.5.). We conclude with the main research outcomes and implications (section 6.6.).

6.2. LITERATURE REVIEW

According to Piatkowski, Krizek and Handy (2015), research analysing modal shift can be divided into two types of studies: indirect inference and direct questioning. Only a handful of studies have assessed the impact of bike sharing on modal shift through indirect inference. Campbell and Brakewood (2017) took advantage of the phased expansion of New York's BSS to measure the impact of bike sharing on bus ridership as a natural experiment, comparing bus routes having BSS stations in their trajectories with bus routes without BSS. The results showed a decrease in bus ridership in routes with BSS stations in their vicinities, compared with bus routes without. Specifically, for every thousand BSS docks along a bus route, a 2.42% decrease in daily unlinked bus trips was observed (Campbell and Brakewood, 2017). Through a similar research design and by using data from the Massachusetts Vehicle Census, Basu and Ferreira (2021) explored the effect of BSS on car ownership and usage in Boston (USA). The authors found that for each new BSS station there was a reduction of 3.3% on vehicle miles travelled (VMT) per person and a 2.2% reduction on car ownership per household, leading to an estimated reduction of 2.9% on vehicular greenhouse gases (GHG) emissions. Furthermore, the car reduction capability of bike sharing was even higher in BSS stations near transit stations, suggesting possible synergies between BSS and PT that could enhance their competitiveness against car use (Basu and Ferreira, 2021).

Most of the available research on the modal shift dynamics induced by bike sharing can be classified into the category of direct questioning. Such studies, by employing travel surveys to the BSS users, enquire respondents about which mode of transport they are replacing with bike sharing, with some studies also asking how bike sharing is influencing the usage of the other modes of transport. For

instance, Ma *et al.* (2020), through an online survey in Delft (the Netherlands), assessed the impact of BSS in the usage of several modes of transport, finding an increase in train usage (with BSS acting as a first/last mile connector) and a decrease in the use of personal cycling, private car, bus/tram and walking. A recent review compiled evidence from 19 studies across the globe that surveyed respondents about the modes replaced by bike sharing, observing that the overwhelming majority of trips substituted were from sustainable transport modes, particularly PT and walking (70% on average), with only a small share being from private car use (around 10% on average) (Teixeira, Silva and Moura e Sá, 2021a). Nevertheless, the study also noticed a substantial variation in car replacing rates, with some systems reporting much higher car reductions than others, leading the authors to recommend further research to assess the factors behind such differences (Teixeira, Silva and Moura e Sá, 2021a).

Understanding the factors behind the decision of some segments of the population to choose bike sharing could potentially be exploited to induce higher car substitution rates. Most of the existent research exploring the main factors influencing bike sharing behaviour mainly focus on assessing the significant factors for joining BSS, not considering possible differences between users replacing different modes of transport (Bachand-Marleau, Lee and El-Geneidy, 2012; Fishman *et al.*, 2014, 2015; Wu *et al.*, 2019; Chen, van Lierop and Ettema, 2020; Reilly, Noyes and Crossa, 2020). Only a handful of studies conducted specific analyses of the factors associated with the modes of transport being replaced by BSS users. Murphy and Usher (2015) investigated the relationship between the observed modal shifts to *Dublinbikes* (Dublin's BSS) and the income of its users, finding that modal shift from car or rail to BSS was associated with higher income groups, while from bus or walking was associated with lower incomes. Yang *et al.* (2016) examined the modal shifts of metro-BSS users (commuters who combined BSS with metro in their journeys) residing in Nanjing (China), including looking at the reasons that led each group to shift to BSS. For former bus passengers and users who used to walk, BSS was more comfortable and provided faster connections, while users who shifted from their personal bicycle reported flexibility and accessibility (contrasting with the inconvenience of carrying their bike on the metro) as major advantages. Former car users mentioned greater travel times and costs, congestion as well as difficulty in finding a parking space as reasons for switching to BSS (Yang *et al.*, 2016). More recently, Barbour, Zhang and Mannering (2019) conducted a survey to BSS users in Florida (USA) in order to explore significant factors affecting the likelihood of bike sharing replacing car trips. The study found respondents who commuted by driving alone or were under 30 years old to be more likely to replace car trips with BSS. Conversely, respondents who spent less than 3 min finding a car parking space or that belonged to a household with a high income or a high car ownership rate were less likely to replace car trips with bike sharing (Barbour, Zhang and Mannering, 2019).

Therefore, there is still a scarcity of studies exploring factors associated with the specific modes of transport being replaced by bike sharing, with the few studies available typically focusing on a very limited number of determinants. Yang *et al.* (2016) is the only known study (to the authors' knowledge) to look at the motivations for each specific type of users according to their modal shift behaviour. However, in addition to being very specific to China's context, their target-population was confined to commuters using BSS to access metro stations (Yang *et al.*, 2016). Furthermore, none of these studies was conducted during COVID-19 and, therefore, the potential impact of COVID-19 on the modal shift behaviour was not considered. Thus, the present study contributes to the existing literature on bike sharing by helping to identify the most significant motivations explaining the modal shift behaviour of BSS users and the effects of COVID-19 on those motivations.

6.3. RESEARCH DESIGN

6.3.1. CASE-STUDY

We used as case-study the BSS of Lisbon, named *GIRA*. Operated by the municipality of Lisbon, *GIRA* was launched at the end of 2017 and it's the largest BSS currently in operation in Portugal, with more than 700 shared bikes distributed across 83 stations, mostly located in the city centre. Among the success features of the system is the availability of electric-assisted bicycles (2/3 are shared e-bikes), that helped to overcome the predominant view of Lisbon being a hilly city and, therefore, not suitable for cycling use (Félix, Moura and Clifton, 2019).

This bike sharing system is part of a broader sustainable push by the municipality of Lisbon aimed at normalizing cycling, which currently represents less than 1% of the city's modal share (Table 25). Concurrently to the BSS implementation, Lisbon has been expanding its cycling network, totalizing already more than 100 km of dedicated cycling lanes and paths, and implementing traffic calming measures. Further expansions of the cycling network and of the BSS have been announced and accelerated during the coronavirus pandemic (Câmara Municipal de Lisboa, 2020a).

Table 25 – Modal split in Lisbon and its Metropolitan Area (AML) in 2017 (INE, 2018)

	Lisbon	AML
<i>Car</i>	45.1%	58.9%
<i>Motorcycle</i>	1.0%	0.9%
<i>Bus</i>	12.2%	8.8%
<i>Metro/Train</i>	8.9%	6.3%
<i>Bicycle</i>	0.6%	0.5%
<i>Walk</i>	29.8%	23.0%
<i>Others</i>	2.4%	1.6%

6.3.2. SURVEY DESIGN AND DATA

We implemented a survey having as target-population the users of *GIRA* with the goal of studying their modal shift behaviour and reasons for using bike sharing. In order to achieve our research objective, we asked respondents to indicate which mode of transport they would have used in their most frequent trip with *GIRA* if the system was not available. We then focused our analysis on exploring possible differences on the motivations for using bike sharing between the different modes of transport replaced (for an overview on the literature of the main motivations for using BSS the reader is invited to consult (Teixeira, Silva and Moura e Sá, 2021b)). A total of 19 motivations were included (Table 27), where respondents were asked to evaluate the influence of each motivation on their decision to use *GIRA* through a 5-point Likert measurement scale from 1 (*not important at all*) to 5 (*very important*). Furthermore, we also enquired our respondents on why they have chosen to use bike sharing instead of a personal bicycle. The respondents were allowed to choose multiple choices from a selection of 9 options (Table 27).

To control for the coronavirus impact on the modal shift dynamics and reasons for using bike sharing, respondents were asked to choose the mode of transport that they would use if *GIRA* was not available and to rate their motivations for using the system before (retrospective questions) and during COVID-19.

The survey was designed through the *limesurvey* platform and was available exclusively online between the months of September and October 2020. We followed an opportunistic sampling, publicizing the survey in cycling and bike sharing groups of Lisbon. The dissemination strategy also involved announcing the survey in the local press, posting on social media platforms (specifically Facebook, Twitter and LinkedIn) including on the official pages and groups of parish councils and residents' associations, as well as sending invitations through university emailing lists. The average completion time was 10 min.

A total of 294 respondents completed the survey, with 259 valid answers in the period before COVID-19 and 195 valid answers in the period during COVID-19. Table 26 presents the main socioeconomic and demographic characteristics of our sample. The majority of our respondents live in Lisbon (86.1%), are male (60.5%), are between 25 and 44 years old (51.7%), have a university degree (86.7%), are employed (72.4%) and have access to a car (78.2%). In order to assess the representativeness of our sample, we also compared it with a larger survey conducted by the system's operator (Moura and Félix, 2019), finding our sample to be, in general, comparable to the operator's survey (please see (Teixeira, Silva and Moura e Sá, 2021b) for a detailed comparison of the two surveys). Overall, the average *GIRA* user is similar to previous research characterizing the average BSS user: male, employed, younger and with a higher education degree (Ricci, 2015).

Table 26 – Sample composition (N=294)

		Frequency	%
Place of residence	Lisbon City	253	86.1%
	Lisbon Metropolitan Area	41	13.9%
Gender	Female	116	39.5%
	Male	178	60.5%
Age (in years)	< 18	3	1.0%
	18-24	47	16.0%
	25-34	82	27.9%
	35-44	70	23.8%
	45-54	74	25.2%
	> 54	18	6.1%
Education	Basic Education	1	0.3%
	Secondary Education	38	12.9%
	Higher Education	255	86.7%
Employment status	Working	213	72.4%
	Not working	13	4.4%
	Retired	5	1.7%
	Studying	63	21.4%
Driving's license	No	33	11.2%
	Yes	261	88.8%
PT monthly pass	No	160	54.4%
	Yes	134	45.6%
Car availability	No	64	21.8%
	Yes	230	78.2%
Bicycle availability	No	122	41.5%
	Yes	172	58.5%

6.3.3. MODELLING APPROACH

We used multinomial logit (MNL) to investigate the relationship between modal shift from different modes of transport and the reasons for using bike sharing. MNL is the most widely employed method to model mode choice (Washington, Karlaftis and Mannering, 2011), including in bike sharing (Wielinski, Trépanier and Morency, 2017; Fan, Chen and Wan, 2019). The standard MNL formulation is the following (Washington, Karlaftis and Mannering, 2011):

$$P_n(i) = \frac{\exp(\beta_i X_{ij})}{\sum_{\forall l} \exp(\beta_l X_l)} \quad (1)$$

Where, β_i is a vector of coefficients to be estimated for the result i and X_{ij} is a vector of the observable characteristics (predictors) that determine discrete outcomes for observation j . As goodness-of-fits measures we used the *Likelihood ratio test* (LR) to confirm that the obtained models are statistically different from the restricted model (constant only) and to compare between them. LR is calculated as $-2(LL(R) - LL(U))$, with $LL(R)$ and $LL(U)$ being the log-likelihood of the restricted and unrestricted model, respectively. The calculated LR is then compared to the χ^2 (as this statistic is asymptotically chi-square distributed) value of the corresponding degrees of freedom. The performance of the models was evaluated using the Cox and Snell, McFadden and Nagelkerke Pseudo- R^2 . For comparison of different specifications, the Akaike Information Criterion (AIC) was used as a measure of the trade-off between the goodness of fit and the simplicity of the model (parsimonious rule): a model with more explanatory variables but higher values of AIC should be rejected, since the additional variables are not adding to the explanatory power of the model. As effects size we used the odds ratio (OR). Odds are defined as the probability of an event occurring divided by the probability of that event not occurring. The odds ratio is the odds of the event in one group divided by the odds in the comparative group (the reference category). Finally, a Wald z -test is performed on the significance of the estimated parameters (Washington, Karlaftis and Mannering, 2011; Field, 2013c).

In our study we considered 3 modes being replaced by bike sharing (private motor vehicle, public transport and walking), which represent, respectively, 85.3% and 80.0% of our samples¹⁴ before and during COVID-19 (Table 28). We included motorcycle together with private car in the category private motor vehicle as it is in the same scale as private car trips regarding CO₂ emissions per passenger (Brand, Dons, *et al.*, 2021). As we are particularly interested in investigating the motivations of car users to shift to BSS due to its negative impacts, we used private motor vehicle as the reference category. To avoid categories with small sample sizes and to minimize problems of incomplete information (*empty cells*) in the modelling procedure we converted our 5-point Likert scale into a binary scale dividing the answers in two categories: *not important* or *important*¹⁵. Thus, the predictors (motivations and the reasons for choosing GIRA instead of a personal bicycle) included in the model were binary. In order to achieve the most parsimonious model, we started by specifying a model with all variables, followed by a backward stepwise procedure that removed predictors considered not important to the fit of the model based on the likelihood ratio test and AIC (Field, 2013c). Finally, predictors whose estimated parameters were not significant (Wald z -test p -value < .1) were also removed. The reference software used in this study

¹⁴ We initially also included the choice personal bicycle, however due to its low share of responses (only 25 respondents selected this option before COVID-19 and 24 during COVID-19) we decided to remove it from the comparison with private motor vehicles. Furthermore, previous studies found that walking and personal bicycle are influenced by different factors and, as such, should not be combined in the same category (Piatkowski, Krizek and Handy, 2015).

¹⁵ Cut-off point: 0 – Not important at all (initially 1 in the original 5-point Likert scale), Slightly Important (initially 2) and Somewhat Important (initially 3); 1 – Important (initially 4) and Very Important (initially 5).

were STATA version 16 and IBM SPSS Statistics version 27. Table 27 presents the full list of variables included in the initial MNL model.

Table 27 – Variables included in the MNL models

Category	Variables	Abbreviation
Dependent Variable	<i>Mode of transport replaced by GIRA (nominal)</i>	
	• Private Motor Vehicle (<i>reference category</i>)	Car
	• Public Transport	PT
	• Walking	Walk
Predictor Variables	<i>Motivations (binary: 0 – not important; 1 – important)</i>	
	• Reductions in travel times	TT
	• Reductions in travel costs	TC
	• Greater trip flexibility	Flex
	• Access to PT	Access_PT
	• Avoid PT	Avoid_PT
	• Environmental concerns	EnvConc
	• Fitness improvement	Fitness
	• Health concerns	HealConc
	• Pleasure of cycling	Pleasure
	• Cycling lanes serving the trip	CycleLane
	• Low car traffic speed in the route	LowTraffic
	• GIRA stations near home	StHome
	• GIRA stations near destinations	StDest
	• Existence of GIRA e-bikes	Ebikes
	• Easiness of using the system	Easiness
	• Influence of people I know	Family
	• Seeing other people using GIRA in the city	OtherPeople
	• Marketing campaigns	Marketing
	• Social distancing	SocialDistanc
	<i>Reasons for choosing GIRA instead of a Personal Bicycle (binary: 0 – not selected; 1 – selected)</i>	
	• Because I don't have a bicycle	No_bike
	• Because it's cheaper than buying a bicycle	Cheaper
	• To avoid the risk of theft	Theft
	• Because there is a lack of bike parking near my destinations	NoBikePark
	• Because I don't have space to store my bicycle at home	NoStorage
	• To avoid maintenance problems	Avoid_mainta
	• Because my bicycle is not electric	No_ebike
	• It's easier to combine with Public Transport	Combine_PT
	• Because I can opt to use it just for a part of my journey whenever it's more convenient to me	Convenient

6.4. RESULTS

6.4.1. DESCRIPTIVE STATISTICS

6.4.1.1. MODAL SHIFT INDUCED BY GIRA

We began by analysing the modal shift to *GIRA* before and during COVID-19 (Table 28).

Table 28 – Modes of transport replaced by *GIRA* users before (N=259) and during (N=195) COVID-19

Modal Shift	Before COVID-19		During COVID-19	
	n	%	n	%
Public Transport	119	45.9%	70	35.9%
Walking	60	23.2%	53	27.2%
Private car	36	13.9%	32	16.4%
Personal bicycle	25	9.7%	24	12.3%
Taxi or equivalent	7	2.7%	9	4.6%
Motorcycle	6	2.3%	1	0.5%
Other	5	1.9%	3	1.5%
New trip	1	0.4%	3	1.5%

We can observe that in both periods, the most replaced mode is PT, followed by walking and the private car. The main difference between the period before and during COVID-19 is related to the share of PT, which has substantially declined (from 45.9% to 35.9%), while the share of users replacing most of the other modes has increase, especially walking (from 23.2% to 27.2%) and the private car (from 13.9% to 16.4%).

In the remainder of the paper, we will focus our analyses on the users replacing PT, walking and private motor vehicle trips (private car and motorcycle) as they are the most replaced modes by BSS.

6.4.1.2. MOTIVATIONS FOR USING GIRA ACCORDING TO THE MODE BEING REPLACED

We conducted a preliminary analysis of possible differences between the users replacing private motor vehicles, PT and walking trips through looking at the percentual distributions of the motivations for using *GIRA*. Figure 36 and Figure 37 represent, respectively, the motivations for using *GIRA* before and during COVID-19, being ranked according to the highest scores of the respondents replacing private motor vehicle trips.

The figures reveal the most important motivation for using *GIRA* both before and during COVID-19, regardless of the replaced mode, to be the existence of stations near their destinations, closely followed by the pleasure of cycling. However, the figures also reveal some significant differences between the users' motivations. Firstly, both before and during COVID-19, greater trip flexibility and seeing other people using the system were more important for users replacing PT or walking trips than for users replacing private motor vehicle trips. On the other hand, the existence of cycling lanes and reductions in travel costs were more important for users replacing motor vehicle trips (both private and PT) than for users replacing walking trips.

In addition, some differences only occurred in one of the periods. Before COVID-19, travel time reductions and the existence of BSS stations near home were more important for users shifting from PT or walking than for users shifting from private motor vehicles. During COVID-19, the importance given to the existence of shared e-bikes by users replacing private motor vehicles was lower in comparison

both with users replacing PT and walking (while for users replacing walking or PT the existence of shared e-bikes was the 2nd most important motivation, for users replacing private motor vehicles this motivation was only the 10th most important). Conversely, using *GIRA* to access PT was found to be more important for users replacing private motor vehicle trips than for users replacing PT or walking trips, while environmental concerns were more important for users replacing motor vehicle trips (both private and PT) than for users replacing walking trips.

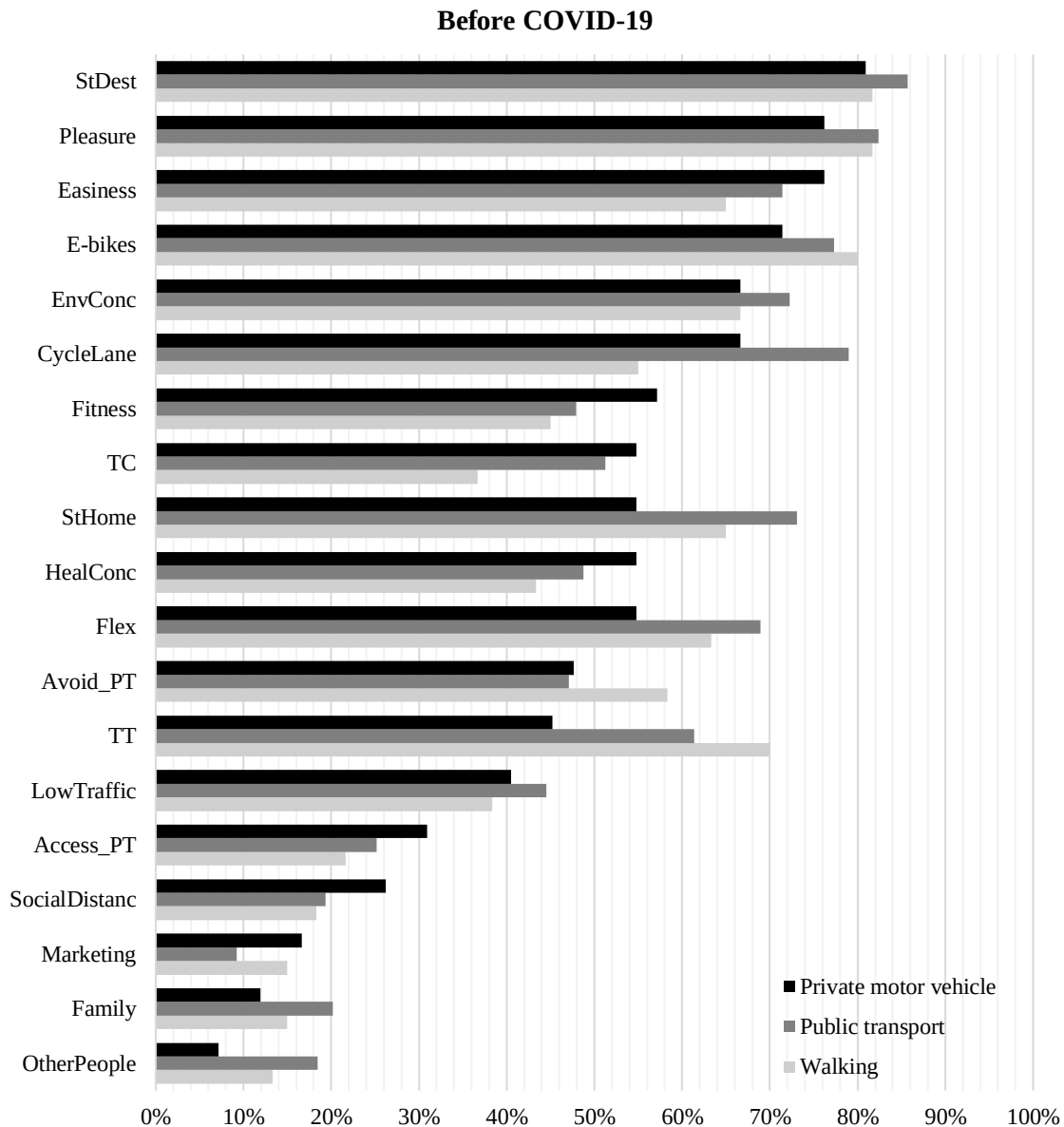


Figure 36 – Comparison of the motivations for using *GIRA* (percentage of respondents considering the motivation important or very important) between users replacing trips from Private motor vehicles (N=42), Public Transport (N=119) and Walking (N=60) **before COVID-19**

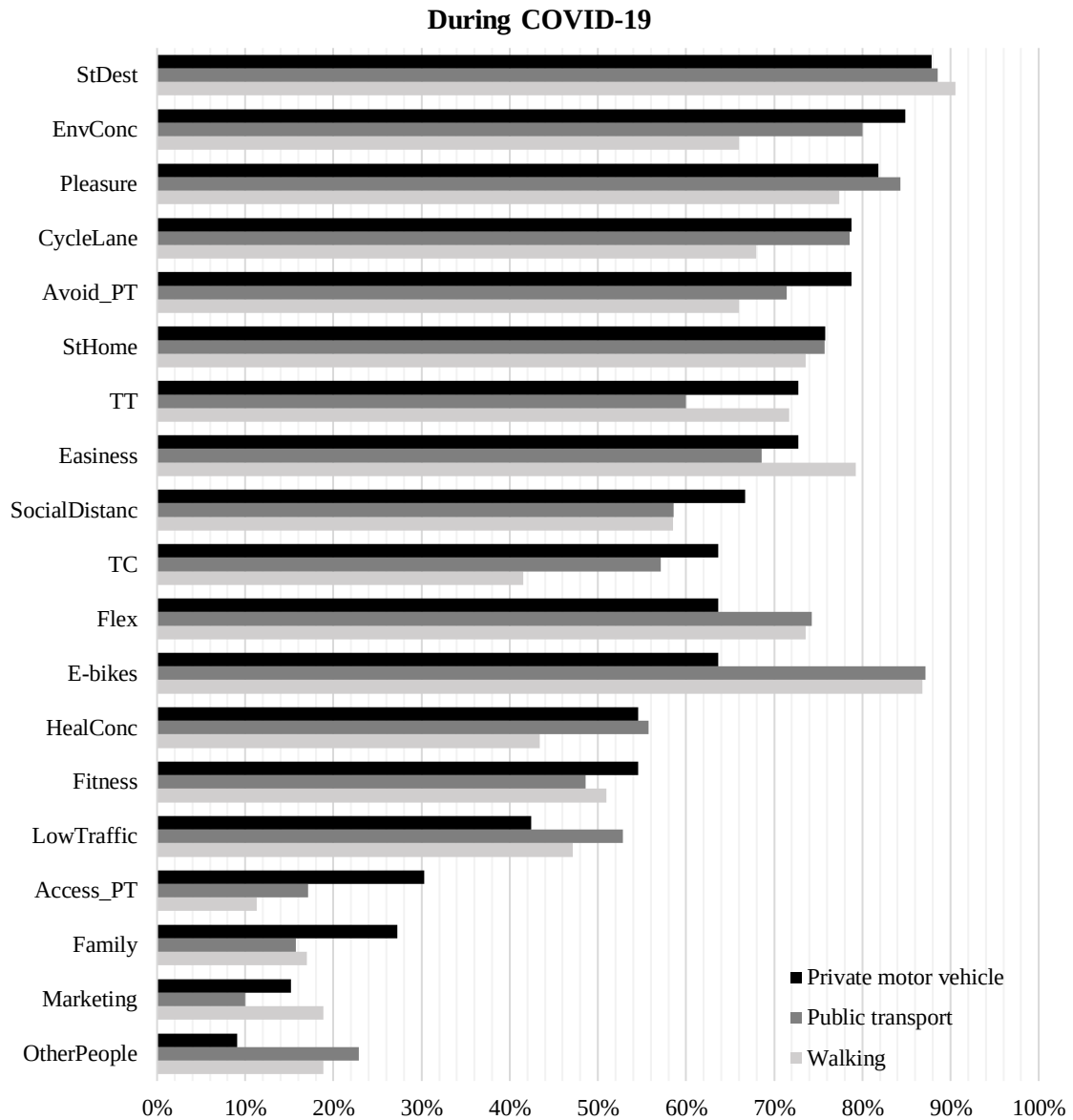


Figure 37 – Comparison of the motivations for using *GIRA* (percentage of respondents considering the motivation important or very important) between users replacing trips from Private motor vehicles (N=33), Public Transport (N=70) and Walking (N=53) **during COVID-19**

6.4.1.3. REASONS FOR CHOOSING *GIRA* INSTEAD OF A PERSONAL BICYCLE

Next, Figure 38 and Figure 39 represent the reasons for choosing *GIRA* instead of a personal bicycle, respectively, before and during COVID-19, being again ranked according to the highest scores of the respondents replacing private motor vehicle trips. The risk of theft was the most chosen reason in the three groups both before and during COVID-19, with the convenience of using bike sharing also considered as a major reason for not using a personal bike. Significant differences were found between the users replacing different modes. Firstly, in both periods, insufficient bike parking facilities near the users' destinations was more frequently chosen by users replacing motor vehicle trips (both private and PT) than by users replacing walking trips. Furthermore, before COVID-19, users replacing PT or walking trips were more likely to choose as reasons the lack of storage space as well as finding BSS

easier to combine with PT comparatively to users replacing private motor vehicle trips. Lastly, during COVID-19, not having an e-bike was more frequently chosen by users replacing private motor vehicle or walking trips than by users replacing PT trips.

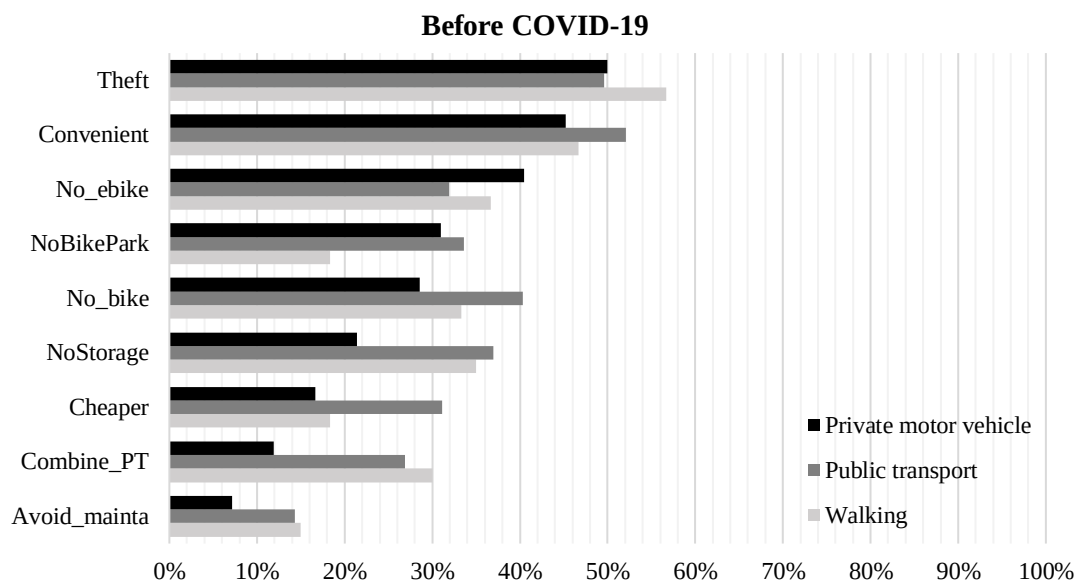


Figure 38 – Comparison of the reasons for selecting *GIRA* instead of a personal bicycle (percentage of respondents that selected each item) between users replacing trips from Private motor vehicles (N=42), Public Transport (N=119) and Walking (N=60) **before COVID-19**

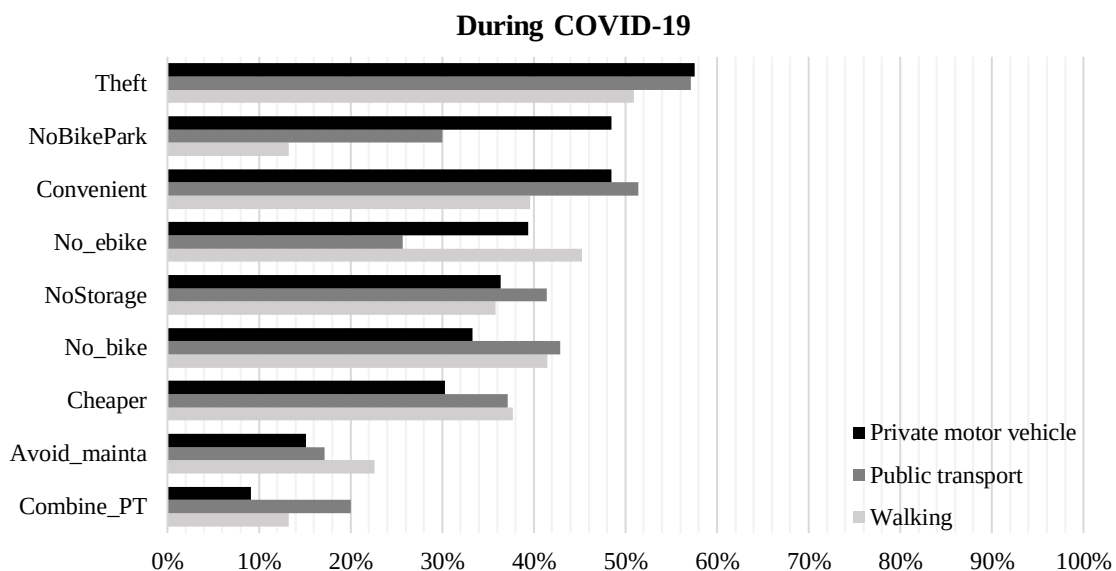


Figure 39 – Comparison of the reasons for selecting *GIRA* instead of a personal bicycle (percentage of respondents that selected each item) between users replacing trips from Private motor vehicles (N=33), Public Transport (N=70) and Walking (N=53) **during COVID-19**

6.4.2. MULTINOMINAL LOGIT (MNL)

To explore the insights of the previous results in more depth we employed MNL models. The final models for the periods before and during COVID-19, including its parameters' estimations and goodness-of-fits measures, are presented, respectively, in Table 29 and Table 30. No multicollinearity issues were detected in both samples (Field, 2013c).

Five predictors were retained in the final model before COVID-19 and six predictors were retained in the final model during COVID-19. Of those, four predictors on the period before COVID-19 and five predictors on the period during COVID-19 were identified as substantially differing between users replacing different modes of transport ($p < .05$). As we have selected as reference category the users replacing private motor vehicle trips, a negative coefficient of a given predictor can be interpreted as the predictor being positively associated with the users replacing private motor vehicle trips and, in those cases, we calculated the inverted odds ratio (1/OR) (Félix, 2019). Predictors with a higher odds ratio (or inverted odds ratio) indicate a larger effect size.

Before COVID-19, only one predictor was found to be positively associated with users replacing private motor vehicle trips. Specifically, reductions in travel costs were associated with a 3.81-fold increase in the odds of replacing private motor vehicle trips comparatively to walking trips. In contrast, three predictors were found to decrease the odds of BSS users replacing private motor vehicle trips. Considering reductions in travel times as important was found to decrease the odds of replacing private motor vehicle trips comparatively both with users replacing PT and walking trips. Likewise, not having space to store a bike at home and considering BSS easier to combine with PT in comparison with using a personal bicycle were also found to decrease the odds of replacing private motor vehicle trips comparatively to users replacing PT or walking trips.

During COVID-19, three predictors were found to be positively associated with users replacing private motor vehicle trips. Considering using *GIRA* to access PT as important was found to increase the odds of replacing private motor vehicle trips in comparison both with PT and walking trips (a 3.37 and 4.08-fold increase, respectively). Like in the pre-pandemic period, considering reductions in travel costs as important was also found to increase the odds of replacing private motor vehicle trips in comparison with walking trips (a 2.81-fold increase). Finally, a lack of bike parking near the destinations was associated with a 4.73-fold increase in the odds of BSS users replacing private motor vehicle trips comparatively to walking trips. In contrast, two predictors were found to decrease the odds of BSS users replacing private motor vehicle trips. Firstly, considering the existence of *GIRA* e-bikes as important was found to decrease the odds of replacing private motor vehicle trips comparatively both with users replacing PT and walking trips. Secondly, seeing other people using *GIRA* in the city was associated with a 4.90-fold increase in the odds of replacing PT trips comparatively with users replacing private motor vehicle trips.

Table 29 – MNL final model for the period **before COVID-19** (N=221)

Variables	B	Std. Error	Wald	Sig.	OR	1/OR	OR 95% CI
Private Motor Vehicle vs Public Transport							
<i>Intercept</i>	0.380	0.343	1.230				
<i>TT</i>	0.960	0.415	5.346	*	2.61		[1.16; 5.89]
<i>TC</i>	-0.594	0.416	2.042		0.55		[0.24; 1.25]
<i>NoBikePark</i>	-0.099	0.407	0.059		0.91		[0.41; 2.01]
<i>NoStorage</i>	1.021	0.449	5.159	*	2.78		[1.15; 6.70]
<i>Combine_PT</i>	1.126	0.539	4.361	*	3.08		[1.07; 8.88]
Private Motor Vehicle vs Walking							
<i>Intercept</i>	-0.223	0.399	0.313				
<i>TT</i>	1.556	0.481	10.451	**	4.74		[1.85; 12.18]
<i>TC</i>	-1.337	0.475	7.937	**	0.26	3.81	[0.10; 0.67]
<i>NoBikePark</i>	-0.891	0.500	3.176		0.41		[0.15; 1.09]
<i>NoStorage</i>	1.046	0.505	4.297	*	2.85		[1.06; 7.65]
<i>Combine_PT</i>	1.289	0.589	4.790	*	3.63		[1.14; 11.51]
LL final model	-206.360		LR χ^2 (22)	30.551	Cox and Snell	0.129	AIC final model 436.7
LL null model	-221.635		Sig χ^2	***	Nagelkerke	0.149	AIC full model 472.6
LL full model	-178.309				McFadden	0.069	Classification 56.6%

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 30 – MNL final model for the period **during COVID-19** (N=156)

Variables	B	Std. Error	Wald	Sig.	OR	1/OR	OR 95% CI
Private Motor Vehicle vs Public Transport							
Intercept	-0.103	0.605	0.029				
TC	-0.362	0.483	0.561		0.70		[0.27; 1.79]
Access_PT	-1.215	0.609	3.989	*	0.30	3.37	[0.09; 0.98]
E-bikes	1.420	0.563	6.357	*	4.14		[1.37; 12.47]
OtherPeople	1.589	0.783	4.121	*	4.90		[1.06; 22.71]
NoBikePark	-0.426	0.477	0.798		0.65		[0.26; 1.66]
Combine_PT	1.459	0.769	3.597		4.30		[0.95; 19.42]
Private Motor Vehicle vs Walking							
Intercept	0.487	0.626	0.607				
TC	-1.032	0.512	4.058	*	0.36	2.81	[0.13; 0.97]
Access_PT	-1.405	0.692	4.123	*	0.25	4.08	[0.06; 0.95]
E-bikes	1.260	0.618	4.153	*	3.52		[1.05; 11.83]
OtherPeople	1.335	0.827	2.605		3.80		[0.75; 19.20]
NoBikePark	-1.553	0.571	7.410	**	0.21	4.73	[0.07; 0.65]
Combine_PT	0.942	0.839	1.262		2.56		[0.50; 13.27]
LL final model	-146.619		LR χ^2 (22)	35.908	Cox and Snell	0.206	AIC final model 321.2
LL null model	-164.573		Sig χ^2	***	Nagelkerke	0.234	AIC full model 360.0
LL full model	-121.978				McFadden	0.109	Classification 58.3%

* $p < .05$ ** $p < .01$ *** $p < .001$

As a summary of the results, Table 31 presents the main associations between the modes of transport replaced by BSS and the reasons for that shift obtained from the MNL models before and during COVID-19. The top of the table represents the reasons found to increase the user's odds of replacing private motor vehicle trips comparatively to PT or walking trips, while the bottom of the table represents the reasons found to decrease the user's odds of replacing private motor vehicle trips comparatively to PT or walking trips. Thus, we can interpret the results as follow:

- Top of the table – If the BSS user considers [reason] as important, he/she is [inverted odds ratio] times *more likely* to be replacing private motor vehicle trips than of replacing [PT or walking] trips
- Bottom of the table – If the BSS user considers [reason] as important, he/she is [odds ratio] times *less likely* to be replacing private motor vehicle trips than of replacing [PT or walking] trips

So, for example, if the user considered seeing other people using the system as an important motivation for using *GIRA*, he/she was 4.90 times less likely to be replacing private motor vehicle trips than of replacing PT trips during COVID-19.

Table 31 – Summary of the main results from the MNL models before and during COVID-19

		Before COVID-19		During COVID-19	
		To be replacing Private Motor Vehicle trips than...		To be replacing Private Motor Vehicle trips than...	
		PT trips	Walking trips	PT trips	Walking trips
Reductions in travel costs	More likely	-	3.81	-	2.81
Access to PT		-	-	3.37	4.08
Lack of bike parking near destinations		-	-	-	4.73
Reductions in travel times	Less likely	2.61	4.74	-	-
Existence of GIRA e-bikes		-	-	4.14	3.52
Doesn't have space to store bike at home		2.78	2.85	-	-
Easier to combine with PT		3.08	3.63	-	-
Seeing other people using GIRA in the city		-	-	4.90	-

6.5. DISCUSSION

This study analysed the differences on the reasons for using bike sharing between users replacing different modes of transport. Users switching from private motor vehicles were more susceptible to travel cost reductions comparatively to users replacing walking trips both before and during COVID-19. This is in line with the study from Yang *et al.* (2016), which also found cost savings to be amongst the major reasons for car users to shift to BSS. Shifting from a private car to BSS can lead to substantial savings, which can be an important motivation especially for lower income groups (Ma *et al.*, 2020; Reilly, Noyes and Crossa, 2020). For example, an annual subscription for *GIRA* costs 25 € (EMEL, 2019b), while, in comparison, the average cost of driving a car in Portugal in 2020 was 649 € per month (including fuel, depreciation, taxes, insurance and maintenance) (LeasePlan, 2020).

Before COVID-19, reductions in travel times were more important to users replacing PT and walking trips than for users replacing private vehicle motor trips. While BSS were found to be travel time competitive with cars in other cities (Jensen *et al.*, 2010; Faghih-Imani *et al.*, 2017), in the case of Lisbon the travel time gains from switching from a car to *GIRA* were not perceived as significant as those from shifting from PT or walking. Interestingly, during COVID-19 this difference has disappeared, with travel time savings increasing in importance for users switching from private motor vehicles (now 72.7% consider it an important motivation comparatively to 45.2% before COVID-19 - Figure 36 and Figure 37), while remaining the same for users switching from PT or walking (see Figure 36 and Figure 37). Such change between the periods may be related to the consequences of the pandemic, particularly the policy response by Lisbon's Municipality that implemented a plan to reallocate space from the car to cycling (and walking). An example was the construction of 76.5 km of new pop-up segregated cycling lanes (Câmara Municipal de Lisboa, 2020a), which may have improved the travel time competitiveness of BSS against the car.

During COVID-19, the existence of shared e-bikes was found to be more valued by users from PT and walking than by users from private motor vehicles. Even though e-bikes' increased range and lower physical effort could increase the competitiveness of BSS and cycling against the car, this seem not to be particularly perceived by these users. As such, the introduction of e-bikes in bike sharing systems may not be enough to induce further modal shift from car drivers. Conversely, using *GIRA* to access PT was found to be more important to users shifting from private motor vehicles than to users shifting from PT and walking. Analysing the percentual distributions of Figure 36 and Figure 37, we can observe that such difference is not so much related to an increase on importance of accessing PT to private motor vehicle users (the percentage remains virtually the same between the two periods), but to a decrease on importance to the users shifting from PT and walking. To understand this finding, we analysed the actual number of respondents combining *GIRA* with PT in their trip before and during COVID-19, dividing them according to the mode being replaced (Figure 40). Analysing Figure 40, the number of respondents combining *GIRA* with PT shifting from walking and PT has decreased between the periods, but the number of respondents shifting from private motor vehicles and combining *GIRA* with PT has actually slightly increased.

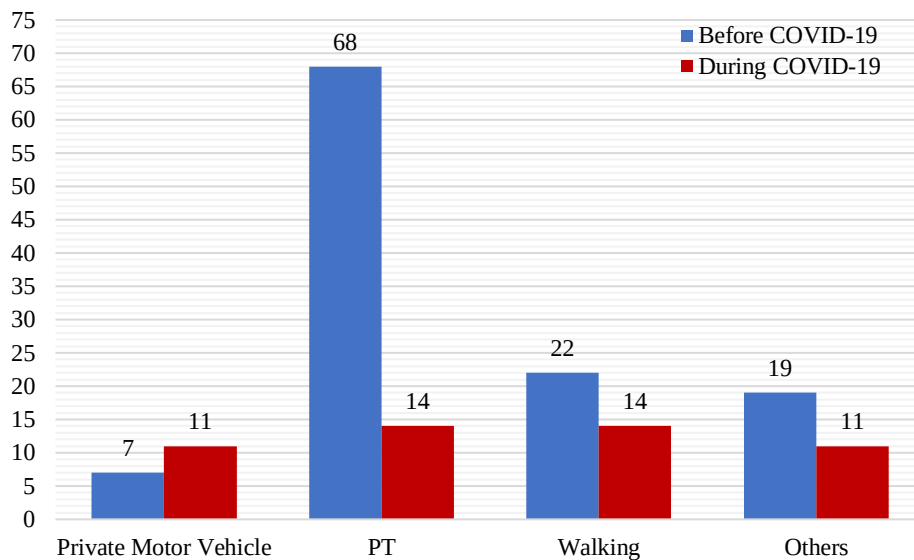


Figure 40 – Number of respondents who combined *GIRA* with PT in their trips before (N=116) and during (N=50) COVID-19, according to the mode of transport replaced

Regarding the reasons for choosing *GIRA* instead of a personal bicycle, two reasons (lack of storage space at home and considering *GIRA* easier to combine with PT) were found to be more associated with users replacing PT or walking than with users replacing private motor vehicles in the period before COVID-19. Users replacing private motor vehicle trips probably have enough storage space for a car or a motorcycle and, therefore, can more easily store a personal bicycle comparatively to users replacing PT or walking, which may not have the same availability of space. The fact that users replacing PT and walking trips were more likely to consider *GIRA* easier to combine with PT before COVID-19 but not during COVID-19 shows, again, the loss of importance to these users of using *GIRA* in combination with PT (Figure 40). Indeed, before COVID-19, 57.1% of users replacing PT and 36.7% of users replacing walking declared to combine *GIRA* with PT, decreasing to only 20.0% and 26.4%, respectively, during COVID-19. In contrast, only 16.7% of users shifting from private motor vehicles declared combining *GIRA* with PT before COVID-19, increasing to 33.3% during COVID-19. As such, the results indicate that users shifting from PT and walking to *GIRA* were more frequently combining *GIRA* with PT, but this relationship was particularly affected by the pandemic.

Finally, concerning the limitations of this study, the survey was distributed through a convenience sampling technique, which was minimized by employing several distribution channels and by comparing the respondents with a representative sample from the operator. Furthermore, the obtained sample sizes were modest, but both samples exceed the recommended minimum ratios of events per variable (Peng, Lee and Ingersoll, 2002; Piatkowski, Krizek and Handy, 2015), while allowing to control for the COVID-19 effect. Assessing the motivations before and during COVID-19 is one of the strengths of this study and, even though, the coronavirus impact was analysed through retrospective questions (which can be affected by recall biases), the disruptive nature of this pandemic makes it realistic to assume that respondents still remembered their past behaviour at the time of the survey (September to October, 2020).

6.6. CONCLUSIONS

Encouraging the modal shift from the car to the bike would lead to several benefits, including reducing the CO₂ emissions of the transport sector. Identifying the key features currently influencing car users to shift to BSS could enable operators to better design their systems to maximize such a shift. This study has allowed the identification of the reasons most valued by private motor vehicle users shifting to BSS comparatively to users replacing PT and walking, as well as changes on those reasons induced by the COVID-19 pandemic.

Policy insights can be derived from this study. BSS operators could take advantage of the travel cost savings' importance to private motor vehicle users by marketing the potential savings of a modal shift to BSS (perhaps by presenting the potential monthly or annual savings of switching from a car to the BSS). Concurrently, policymakers may consider increasing the cost of car usage, (e.g., through increasing car parking charges in the catchment areas of BSS stations) as a possible approach to induce further car modal shift to BSS. Another population segment with potential for change could be commuters using the car to access public transport as illustrated by our findings, on which among the users combining BSS with PT those shifting from private motor vehicles were less affected than those shifting from PT or walking. Indeed, this is a strategy already followed in the Netherlands with the *OV-fiets* system, which was specifically implemented to provide a first/last mile connection to train stations and has been found to successfully replace car trips (Villwock-Witte and van Grol, 2015).

Moreover, several motivations, such as the suitable location of BSS stations near the users' destinations and the pleasure of cycling, were found to be very important to all BSS users regardless of the modes

that they are replacing. Thus, operators should consider these universal features when designing their marketing campaigns for promoting BSS usage. Likewise, although the availability of shared e-bikes was more important to users replacing PT or walking trips, adding e-bikes to BSS continues to be a measure worth following as they are usually provided at a very affordable usage cost compared to buying an e-bike. Indeed, one of the main reasons stated by our respondents for using BSS instead of a personal bicycle was the lack of a personal e-bike (even amongst those replacing private motor vehicles).

Additionally, this study provides evidence on the advantages of BSS against personal bicycles. Bike theft was found to be the most chosen reason regardless of the replaced mode. Therefore, the provision of shared bikes addresses bike theft concerns, which is a common problem in several cities and can be a significant barrier for people to cycle (Rietveld and Daniel, 2004; Sidebottom, 2012). Likewise, the ability of using BSS in the part of the journey considered to be the most convenient was highly regarded by BSS users. As explained by Fishman (2019), one of BSS major advantages is offering the user the ability of making one-way cycling trips in the part of the journey that makes more sense to cycle (which also makes it easier to combine with PT). Such advantages of BSS against personal bicycles can potentially induce new users to take up cycling who otherwise wouldn't cycle.

Future studies with larger samples could analyse the motivations of users replacing additional modes of transport such as the personal bicycle, as well as explore possible differences between users replacing different PT modes (e.g., comparing train, metro and bus). Moreover, larger sample sizes would allow the inclusion of additional variables such as the socioeconomic and demographic profile of BSS users as well as spatial (built and natural) characteristics surrounding the BSS stations. Qualitative research could also be employed to further explore the motivations leading different types of users to shift to BSS, allowing to discuss in depth this type of data not easily captured by the close-ended responses that characterize travel surveys. Lastly, similar studies could be conducted among non-users to understand their views on BSS and on how to induce larger swaths of the population to shift to bike sharing.

7.

THE STRENGTHS AND WEAKNESSES OF BIKE SHARING AS AN ALTERNATIVE MODE DURING DISRUPTIVE PUBLIC HEALTH CRISIS: A QUALITATIVE ANALYSIS ON THE USERS' MOTIVATIONS DURING COVID-19

This chapter presents an integral reproduction of: “Teixeira, J. F., Silva, C. and Moura e Sá, F. (2022) ‘The strengths and weaknesses of bike sharing as an alternative mode during disruptive public health crisis: A qualitative analysis on the users’ motivations during COVID-19’, Transport Policy. Elsevier. 129, pp. 24–37. doi: 10.1016/j.tranpol.2022.09.026.”

ABSTRACT

The coronavirus pandemic may provoke an increase on our overreliance on private car usage due to a permanent loss of confidence on public transport (PT), threatening current decarbonization efforts of the transport sector. Thus, alternative modes like bike sharing systems (BSS) must be considered.

In this study, through conducting 16 semi-structured interviews and by employing thematic analysis, we explore the users’ perceptions of using Lisbon’s BSS during this pandemic. Our findings show that the observed decrease on BSS usage during the COVID-19 lockdowns was mostly due to mandatory teleworking than to a perceived infection risk. Even during the height of the pandemic, users still turned to BSS to fulfil their essential trip needs. Users considered bike sharing to have a lower infection risk comparatively to PT, with some users joining BSS during the pandemic to specifically avoid using PT. Furthermore, users associate riding a shared bicycle with a pleasant activity that reduces their travel times and costs, while also providing health and environmental benefits. Consequently, bike sharing contributes to the resilience of transport systems by providing its users with a transport alternative perceived to have a low infection risk, ensuring their mobility needs during disruptive events.

Findings from this research provide evidence that support policies, such as, expanding BSS coverage areas, optimizing rebalancing operations, introducing shared e-bikes, and implementing segregated cycling lanes alongside BSS. These policies may be particularly effective at increasing the competitiveness of BSS as an alternative mode during disruptive public health crises and beyond.

KEYWORDS: Coronavirus; Bike sharing; Qualitative methods; Thematic analysis; Semi-structured interviews

7.1. INTRODUCTION

The coronavirus pandemic presents serious challenges for the transport sector. Public transport (PT) systems have been especially affected by COVID-19 due to the infection fear of having large numbers of passengers in confined spaces for long periods of time, leading to massive ridership drops (Gkiotsalitis and Cats, 2020; Teixeira and Lopes, 2020). Even during the periods where COVID-19 seemed under control and no travel restrictions were in effect, PT ridership remained well below pre-pandemic levels, showing disturbing signs that users may have lost confidence on PT systems (Medlock, Temzelides and Hung, 2021). For example, in New York City during the summer of 2021 when COVID-19 infection rates were low (NYC Health, 2021), subway and bus ridership were still 50% and 60%, respectively, of the pre-pandemic levels (MTA, 2021).

As epidemiologists start to consider the possibility that the coronavirus will become endemic (Phillips, 2021), the question may not be how long it will take to PT ridership to recover to pre-pandemic levels, but rather if it will recover at all. Such a permanent PT ridership loss would have severe consequences particularly regarding current decarbonizing efforts. The transport sector is a major source of CO₂ emissions, with private car usage being by far the main culprit (Graham-Rowe *et al.*, 2011; Brand, Dons, *et al.*, 2021). Indeed, car usage has been much less affected than PT during this pandemic, registering lower ridership drops and being perceived as having a lower risk of infection (de Haas, Faber and Hamersma, 2020; Shamshiripour *et al.*, 2020). Consequently, this pandemic could further exacerbate our current overreliance on car travel.

Cycling has been positioning itself as an alternative, with cycling levels increasing in several countries during COVID-19 (Buehler and Pucher, 2021; Kraus and Koch, 2021). In this study we look at one of the most popular measures promoting cycling: bike sharing systems (BSS). Characterized by providing bicycles either at stations or within operational areas, BSS are known for their convenience and affordability, being associated with increasing both the number and the diversity of cyclists (Teixeira, Silva and Moura e Sá, 2021a). BSS have already been shown to be able to reduce private car usage (Teixeira, Silva and Moura e Sá, 2021a), and to be a transport alternative during disruptive events such as PT strikes (Saber *et al.*, 2018).

As such, it is paramount not only to investigate how coronavirus is impacting bike sharing, but also what can be the potential role of BSS during this pandemic and similar disruptive public health crises. In that sense, the use of qualitative methods could deliver important insights on the disruptive impacts that COVID-19 has provoked on travel behaviour, providing rich, in-depth data on BSS users' motivations and attitudes which is not easily captured by quantitative approaches (Clifton and Handy, 2003; Beirão and Sarsfield Cabral, 2007). Consequently, the objectives of this research were twofold. Firstly, we aimed at analysing the major COVID-19 impacts on the travel behaviour as well as the motivations and safety perceptions of BSS users, better understanding why they have chosen to use bike sharing during the pandemic instead of other available modes of transport. Secondly, we assessed the strengths and weaknesses of bike sharing to identify the features that could increase the competitiveness of BSS as an alternative mode during disruptive public health crisis like COVID-19 and beyond. Through conducting semi-structured interviews to the users of Lisbon's BSS (entitled *GIRA*) and by employing thematic analysis, we present, to the best of our knowledge, the first qualitative study focused on examining the effects of COVID-19 on BSS users.

The rest of the paper is structured as follows. Section 7.2. provides a literature overview of the potential benefits of bike sharing (7.2.1.) and the main reasons for (not) using BSS (7.2.2.), with a special emphasis on the contribution of qualitative studies (7.2.3.), as well as on the existing research exploring the COVID-19 impacts on BSS (7.2.4.). Section 7.3. briefly describes the case-study (7.3.1.) and the

employed methodology (7.3.2.). Section 7.4. presents the results of the thematic analysis, which are then discussed in section 7.5. Lastly, section 7.6. explores the main conclusions, ending with policy recommendations aimed at improving BSS.

7.2. LITERATURE REVIEW

7.2.1. THE (POTENTIAL) BENEFITS OF BIKE SHARING

Embodying the modernistic “ideals of freedom, privacy, movement, progress and autonomy” (Böhm *et al.*, 2006), the car has throughout the last century dominated our transport systems and reshaped our urban areas (Urry, 2004; Bart, 2010). Fostered by planning processes and transport models focused on the paradigm of *predict and provide* (Owens, 1995), automobility has marginalized other modes of transport such as PT, walking and cycling (Cox, 2008; Koglin and Rye, 2014). However, such overreliance on private car travel has led to several negative consequences, including regarding climate change (Douglas *et al.*, 2011; Gössling, 2020).

Consequently, there is a growing pressure to promote a more sustainable mobility through challenging the current automobility regime (Ogilvie *et al.*, 2004; Urry, 2004; Graham-Rowe *et al.*, 2011). In that regard, cycling is amongst the most promising solutions to tackle this car dependency, especially in urban areas (Pucher and Buehler, 2008), being amongst the most efficient decarbonization policies (Brand, Dons, *et al.*, 2021; Brand, Götschi, *et al.*, 2021). For instance, a recent study estimated that if countries cycled as much as the Netherlands, it could lead to a reduction of 686 million metric tons of CO₂ emissions and prevent 0.62 million deaths per year (Wu Chen *et al.*, 2022). Moreover the bicycle also shares most of the same modernistic ideals of the car such as the freedom of movement and autonomy (Cox, 2008), with bicycles capable of being even faster than cars in urban areas (Jensen *et al.*, 2010).

However, the pervasive nature of automobility that dominates not only our current transport systems but also our planning practices and culture (Urry, 2004; Cox, 2008; Koglin and Rye, 2014; Haustein *et al.*, 2020), hinders any transition to alternative mobility cultures (Koglin, 2015). Indeed, even in cities where cycling usage is widespread such as Copenhagen, the car continues to dominate (Freudendal-Pedersen, 2015b, 2015a; Haustein *et al.*, 2020). Taking inspiration from the concept of biodiversity, Cox (2008) argues that we are currently facing a automobility monoculture, where the car is the default transport alternative for most citizens, suggesting that a possible way to challenge this automobility dominance is by introducing alternative modes of transport. In that sense, the meteoric rise of bike sharing in the last two decades, with BSS currently deployed in more than 1000 cities and providing more than 10 million shared bikes (Meddin Bike-sharing World Map, 2021), could offer such alternative.

Several benefits have been attributed to bike sharing, namely its ability to reduce CO₂ emissions and other air pollutants, increase physical activity levels, induce travel time savings and decrease congestion levels (Teixeira, Silva and Moura e Sá, 2021a), provided that BSS are replacing car trips which is not always the case (Médard de Chardon, 2019). Amongst the most promising benefits of BSS is their potential ability to increase cycling levels and normalize cycling usage in low-cycling contexts (Goodman, Green and Woodcock, 2014; Teixeira, Silva and Moura e Sá, 2021a). For example, New York City's BSS is responsible for around 10% of the city's cycling trips, even though the system is still mostly confined to the city core (Department of Transportation NYC, 2018). Bike sharing has also been associated with reversing the decline of cycling usage in China (Mobike, 2017) with, for instance, Beijing's dockless BSS accounting for over 1.5 million trips per day and having more than 11 million users (which corresponds to half the city's population) (Chai *et al.*, 2021).

Importantly, bike sharing has been associated with increasing the diversity of cyclists (Goodman, Green and Woodcock, 2014) and to enhance the public legitimacy of cycling (Fishman, Washington and Haworth, 2012). For example, through observing the clothing of BSS users comparatively to cyclists using their own bike in London, Goodman, Green and Woodcock (2014) found that BSS users were much less likely to use any type of specialist cycling clothing (such as helmets and sports clothes). Seeing other people cycling (Fishman, Washington and Haworth, 2012), particularly “people like yourself”, could help to attract potential cyclists that avoid cycling due to it being perceived as an activity for “sporty” people and not for them (Aldred, 2013; Goodman, Green and Woodcock, 2014).

7.2.2. OVERVIEW OF THE MAIN REASONS FOR JOINING BIKE SHARING

Mostly through conducting travel behaviour surveys, researchers enquired BSS users regarding their motivations for using bike sharing, with a smaller number of studies also investigating the reasons of non-users for not joining BSS. We present in Table 32 an overview on the main literature findings regarding the reasons for (not) using bike sharing.

Users cite several reasons for joining bike sharing. Convenience is often referred to as the major motivation for using BSS (Ricci, 2015; Fishman, 2016). For example, a survey targeting users and non-users of bike sharing in two Australian cities (Brisbane and Melbourne) found that the convenience of using bike sharing was the most important motivation, while for non-users their main justification for not joining BSS was that other modes of transport (such as the car) were more convenient to use (Fishman *et al.*, 2014). Convenience is in addition closely related to the suitable location of BSS stations near users' homes and destinations (Bachand-Marleau, Lee and El-Geneidy, 2012; Fishman *et al.*, 2015; Raux, Zoubir and Geyik, 2017; Hosford *et al.*, 2018) as well as the easiness of using the system itself (Fishman, Washington and Haworth, 2012; Chen and Lu, 2016; Wu *et al.*, 2019).

Furthermore, users associate bike sharing with reductions on their travel time (Fishman *et al.*, 2014; Reilly, Noyes and Crossa, 2020) and costs (TfL, 2011; Ma *et al.*, 2020; Reilly, Noyes and Crossa, 2020). For instance, the users' surveys of London's BSS conducted by TfL (2011) revealed that the main motivation, among members, to join the scheme was BSS being quicker than their previous mode of transport.

The pleasure of cycling is also a major motivation for using bike sharing (Fishman *et al.*, 2014; Chen, 2016; Wu *et al.*, 2019), with BSS being perceived as an environmentally friendly and healthy transport option (TfL, 2011; Fishman *et al.*, 2014; Chen and Lu, 2016; Hosford *et al.*, 2018; Wang *et al.*, 2018; Cerutti *et al.*, 2019). For example, Kim *et al.* (2017) surveyed residents of Suwon (South Korea) about their willingness to pay, through taxes, the promotion of the city's BSS, being informed of the environmental and health benefits of the system. The authors observed that the perception of the BSS value was directly influenced by the awareness of the system's environmental and health benefits.

Lastly, the perceived social acceptance of using bike sharing plays an important role (Wang *et al.*, 2018; Chen, van Lierop and Ettema, 2020), with the trendy status (Bachand-Marleau, Lee and El-Geneidy, 2012) and seeing other people using BSS in the city (Fishman, Washington and Haworth, 2012) having a positive influence on BSS usage.

Conversely, there are also several barriers associated with BSS usage. The main reasons not to join BSS provided by non-users are connected to other modes of transport being more convenient, especially the car (Fishman *et al.*, 2014), with the speed and ease of signing up to a BSS also having impacts on the probability of using the systems (Fishman, 2016). Moreover, mandatory helmet laws are associated with lower BSS usage rates (Ricci, 2015; Fishman, 2016). However, the major barrier for BSS adoption

seems to be related to safety concerns which are particularly connected to having to cycle together with motorized traffic without dedicated cycling infrastructure and having to endure dangerous behaviours from car drivers (Fishman, Washington and Haworth, 2012; Bateman *et al.*, 2021).

Table 32 – Summary of the current literature on the main motivations and barriers for using bike sharing

Reasons for (not) using BSS	Main Findings	References
<i>Convenience (related to availability, usefulness, spontaneity, easiness of use)</i>	Major reason for BSS usage for all users Car convenience is a barrier Perceived ease of use <i>positively</i> influences positive attitudes towards BSS	Fishman, Washington and Haworth (2012) (F) ; Fishman <i>et al.</i> (2014) (S) ; Ricci (2015) (R) ; Chen and Lu (2016) (S) ; Fishman <i>et al.</i> (2014); Ricci (2015); Fishman (2016) (S) ; Wu <i>et al.</i> (2019) (S)
<i>BSS stations close to O/D</i>	Motivation for BSS use (related to convenience)	Bachand-Marleau, Lee and El-Geneidy (2012) (S) ; Fishman <i>et al.</i> (2015) (S) ; Raux, Zoubir and Geyik (2017) (S) ; Hosford <i>et al.</i> (2018) (S)
<i>Reductions on travel times</i>	Motivation for BSS use	TfL (2011) (S) ; Fishman <i>et al.</i> (2014) (S) ; Reilly, Noyes and Crossa (2020) (S)
<i>Financial savings</i>	Among the motivations for BSS use for some users	TfL (2011) (S) ; Ma <i>et al.</i> (2020) (S) ; Reilly, Noyes and Crossa (2020) (S)
<i>Enjoyment/pleasure of cycling</i>	Major motivation for BSS use Perceived fun to use is <i>positively</i> associated with users' continuing to use BSS	Fishman <i>et al.</i> (2014) (S) ; Chen (2016) (S) ; Wu <i>et al.</i> (2019) (S)
<i>Environmental benefits</i>	Among the motivations for BSS use Associated with intention to use and to continue to use	TfL (2011) (S) ; Fishman <i>et al.</i> (2014) (S) ; Chen and Lu (2016) (S) ; Kim <i>et al.</i> (2017) (S) ; Hosford <i>et al.</i> (2018) (S) ; Wang <i>et al.</i> (2018) (S) ; Cerutti <i>et al.</i> (2019) (S)
<i>Health benefits</i>	Health/exercising among the motivations for BSS use Perceived health gains (physical and mental) influence positive attitudes towards BSS	TfL (2011) (S) ; Fishman <i>et al.</i> (2014) (S) ; Kim <i>et al.</i> (2017) (S) ; Hosford <i>et al.</i> (2018) (S) ; Cerutti <i>et al.</i> (2019) (S)
<i>Safety</i>	Lack of cycling infrastructure and dangerous driving behaviour are reasons for <i>not</i> using BSS	Fishman, Washington and Haworth (2012) (F) ; Bateman <i>et al.</i> (2021) (F)
<i>Helmet use</i>	Barrier for BSS use in countries where helmet is mandatory	Ricci (2015) (R) ; Fishman (2016) (R)
<i>Social influence</i>	The attractive design of the bikes as well as seeing people using them <i>positively</i> influence BSS use	Bachand-Marleau, Lee and El-Geneidy (2012) (S) ; Fishman, Washington and Haworth (2012) (F) ; Wang <i>et al.</i> (2018) (S) ; Chen, van Lierop and Ettema (2020) (S)

(F) – Focus group; **(I)** – Interview; **(R)** – Literature review; **(S)** – Survey

7.2.3. THE IMPORTANCE OF QUALITATIVE STUDIES FOR UNDERSTANDING BSS USAGE

Although representing only a fraction of the existent studies on BSS, qualitative research has delivered valuable in-depth insights into the decision to use or not bike sharing. Arguably the most influential qualitative study on bike sharing was developed by Fishman, Washington and Haworth (2012) with the aim of identifying motivations and barriers for using BSS in Brisbane (Australia). Employing thematic analysis and focus groups, which were categorized according to the type of cyclists (non and infrequent cyclists; regular cyclists; BSS users), Fishman, Washington and Haworth (2012) found that the reasons for (not) using Brisbane's BSS revolved around three major themes: accessibility and spontaneity; safety; weather and topography. Also through thematic analysis, Lyu *et al.* (2021) conducted semi-structured interviews to the BSS users of Shanghai (China), providing an unique view from a city that was amongst the first to experience the rise (and fall) of the *dockless* systems. Among others, the study revealed the major problems of Shanghai's BSS to be related to the poor quality of the bicycles due to vandalism and inadequate maintenance; rebalancing issues; as well as the fact that several *dockless* systems abruptly closed due to bankruptcy, leading users to lose confidence on the systems (Lyu *et al.*, 2021). Similarly to the previous two studies, Bateman *et al.* (2021) assessed the motivators and barriers for BSS usage in Alabama (USA), classifying the barriers and motivators as intrapersonal, interpersonal and as structural factors. Bateman *et al.* (2021) found that the most important motivations influencing BSS usage were not so much connected to intrapersonal or interpersonal factors (like the pleasure of cycling or the support from friends and family) but to structural ones such as the coverage of the system and features of the built environment (like the existence of dedicated cycling lanes).

7.2.4. THE CORONAVIRUS PANDEMIC AND BSS USAGE

A growing body of literature is revealing BSS to be more resilient than other modes of transport, particularly PT, to the current coronavirus pandemic, suffering lower ridership drops (Bucsky, 2020; Teixeira and Lopes, 2020; Hu *et al.*, 2021) and registering faster recovery rates (Hu *et al.*, 2021; Wang and Noland, 2021), with ridership recovering and even surpassing pre-pandemic levels (Wang and Noland, 2021). Moreover, several BSS registered an increase in their average trip durations during the pandemic (Teixeira and Lopes, 2020; Hu *et al.*, 2021; Padmanabhan *et al.*, 2021; Shang *et al.*, 2021), with preliminary research pointing to some PT users shifting to bike sharing (Teixeira and Lopes, 2020).

In order to better understand the reasons for the BSS relative resilience to the pandemic, a smaller number of studies has started to analyse the effects of COVID-19 on the travel behaviour of BSS users through surveys (Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour *et al.*, 2020; Teixeira, Silva and Moura e Sá, 2021b, 2022a). The emerging trend from such studies seems to point that bike sharing is considered to have a lower infection risk comparatively to public transport, but is perceived as less safe than using personal modes such as the private car (Nikiforiadis, Ayfantopoulou and Stamelou, 2020; Shamshiripour *et al.*, 2020; Teixeira, Silva and Moura e Sá, 2022a). For instance, through using a travel survey aimed at the BSS users of Lisbon, Teixeira, Silva and Moura e Sá (2021b, 2022) found that users now value much more using BSS to avoid PT and to maintain a social distance during their trips, leading the authors to hypothesize that BSS could provide an alternative to PT during COVID-19.

Building on this previous research, in this study we conducted semi-structured interviews with BSS users from Lisbon to explore in more depth the individual behavioural changes provoked by coronavirus, particularly regarding their motivations and attitudes. Furthermore, this research aims to use the detailed

data provided by qualitative methods to better understand the reasons that lead users to choose bike sharing instead of other available modes of transport. For instance, inconveniences associated with specific modes of transport previously used can be a major motivation for shifting to BSS, however that concept varies according to the mode of transport being replaced. For former car users, perhaps, the difficulty in finding car parking or enduring traffic jams could explain their decision to shift to bike sharing, while for former PT users overcrowding could be a major motivation. Accordingly, the setting of a semi-structured interview will provide the opportunity to discuss in depth more specific types of motivations, not easily captured by the close-ended responses that characterize travel surveys, and which have been so far insufficiently addressed in the literature.

7.3. STUDY DESIGN

7.3.1. CASE-STUDY

As case-study we used the bike sharing system of Lisbon, named *GIRA*. Lisbon is the capital of Portugal and, like the rest of the country, is heavily reliant on car use with 45% of all commuting trips being conducted by car, while cycling represents less than 1% of the modal share (INE, 2018). As such, Lisbon can be classified as a starter cycling city, i.e., a city with a residual cycling shares characterized by having poor cycling conditions and no cycling tradition (BYPAD, 2008; Silva *et al.*, 2019).

To reduce car usage in the city, since 2016 Lisbon has started to promote cycling as a mode of transport, mainly through developing a 200 km dedicated cycling network (mostly constituted by cycling lanes and paths segregated from motorized traffic) and by implementing a public-owned docked BSS (Câmara Municipal de Lisboa, 2020b). Nevertheless, most of the city's transport infrastructure (and public space) continues to be allocated to the car. Figure 41 presents the location of the *GIRA* stations and the existing cycling network. *GIRA* currently has around 700 shared bikes (most being e-bikes) distributed among 83 stations, which are mainly concentrated in the city centre and riverside.

Regarding the impact of COVID-19 on *GIRA*'s operation, the system was initially closed during the first COVID-19 lockdown¹⁶ on March 18th, 2020 (EMEL, 2020c). However, *GIRA* was reopened just three days later to support essential workers such as healthcare professionals, security personal as well as food-delivery couriers (EMEL, 2020a, 2020b). Since then, *GIRA* remained open, including during the second full lockdown in 2021, operating normally with enhanced cleaning protocols.

Figure 42 presents the percentage difference between *GIRA*'s monthly ridership in 2020 versus in 2019, comparing it with the reported number of new COVID-19 daily cases throughout 2020 (monthly average) in Portugal. The figure shows an overall trend in which *GIRA* ridership tends to decrease when COVID-19 daily cases increase. The system registered the largest ridership drops during the height of the first lockdown, culminating in an historic 65% ridership drop in April 2020 comparatively to the same period in 2019. However, with the end of the first lockdown, in May 2020, *GIRA*'s ridership quickly bounced back even surpassing pre-pandemic levels during the summer months. As the number of daily COVID-19 cases started again to rapidly increase in the beginning of autumn 2020, *GIRA* ridership levels declined again but at a lower rate when compared to the first wave (April 2020).

¹⁶ To date, Portugal has experienced two full lockdowns as a response to the COVID-19 pandemic, which included in both cases stay-at-home orders, where only essential trips were allowed. The first lockdown was implemented between March 18th and May 2nd, 2020, while the second lockdown between January 15th and March 15th, 2021. In both cases the lockdown easing was gradual with several reopening phases.

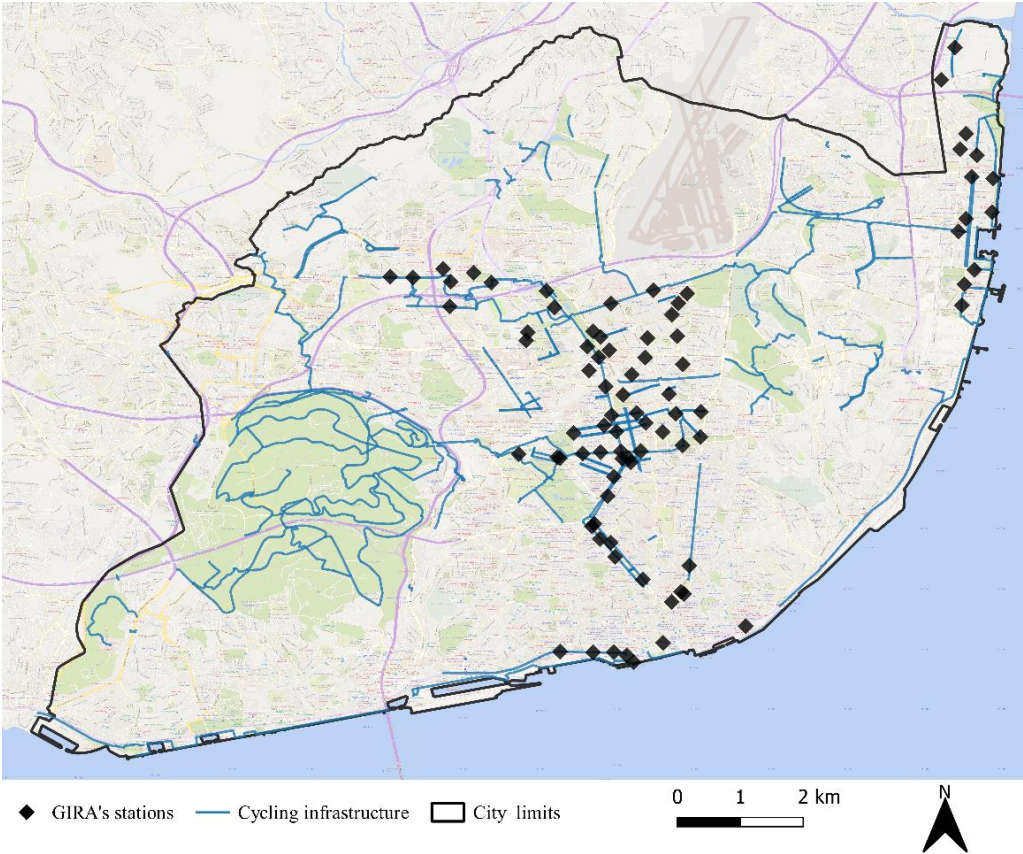


Figure 41 – Distribution of *GIRA*'s stations across Lisbon (background: Bing Maps)

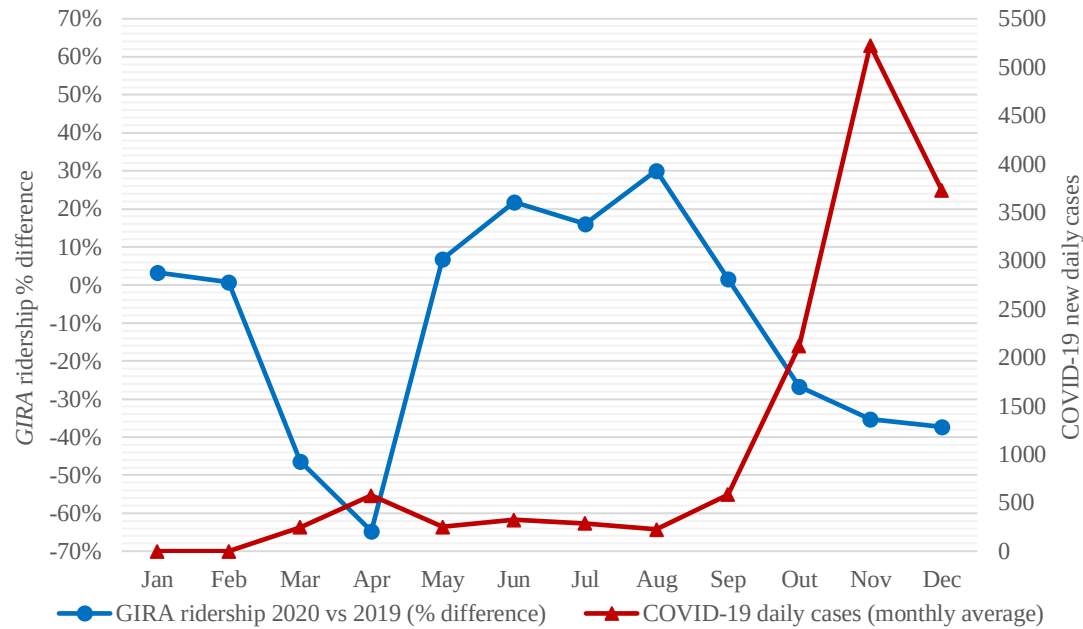


Figure 42 – Percentage difference on *GIRA*'s monthly ridership between 2020 and 2019 versus the number of COVID-19 new daily cases (monthly average) throughout 2020 in Portugal (DGS, 2021)

7.3.2. DATA COLLECTION AND ANALYSIS

In this study, semi-structured interviews were conducted following the implementation of a travel survey to the users of *GIRA* (Teixeira, Silva and Moura e Sá, 2021b, 2022a) to explore in more depth the COVID-19 impacts on their travel behaviour, preferences and motivations. As such, the interviewees were recruited through the previously mentioned survey, which had an option at the end for respondents interested in participating in a second research phase to leave their contact details. Invitations for study participation were sent to the respondents who provided valid emails (63 in total), with 16¹⁷ individuals agreeing to be interviewed.

The interviews were conducted between 4 and 19 of November, 2021, through videocall with an average duration of 15 min. The interviews were recorded and transcribed verbatim. A series of questions (mostly open-ended) were asked to the participants focused on the reasons for their decision to use *GIRA*, the impacts of COVID-19 on that usage as well as *GIRA*'s relationship with other modes of transport (the list of the interview questions can be found in Appendix A5).

The profile of the interviewees is provided in Table 33. Most participants were already *GIRA* users before COVID-19 and continue to currently use the system, while two interviewees reported to have joined *GIRA* during the pandemic. Regarding the sociodemographic profile of interviewees, more than half were male, with their ages ranging from 25 to 64 years old (the majority between 25 and 44 years old), and with only one interviewee not currently working.

Table 33 – Profile of interviewees

	Type of <i>GIRA</i> User	Gender	Age Bracket	Working Status
Interviewee 1	User before & during COVID-19	Female	35 – 44	Working
Interviewee 2	New User	Female	25 – 34	Working
Interviewee 3	User before & during COVID-19	Male	45 – 54	Working
Interviewee 4	User before & during COVID-19	Male	35 – 44	Not working
Interviewee 5	User before & during COVID-19	Male	35 – 44	Working
Interviewee 6	User before & during COVID-19	Male	35 – 44	Working
Interviewee 7	User before & during COVID-19	Female	25 – 34	Working
Interviewee 8	User before & during COVID-19	Female	55 – 64	Working
Interviewee 9	User before & during COVID-19	Male	55 – 64	Working
Interviewee 10	User before & during COVID-19	Female	25 – 34	Working
Interviewee 11	New User	Male	35 – 44	Working
Interviewee 12	User before & during COVID-19	Female	35 – 44	Working
Interviewee 13	User before & during COVID-19	Male	45 – 54	Working
Interviewee 14	User before & during COVID-19	Male	25 – 34	Working
Interviewee 15	User before & during COVID-19	Male	25 – 34	Working
Interviewee 16	User before & during COVID-19	Female	45 – 54	Working

We employed thematic analysis to interpret and structure the data obtained from the interviews, following Braun and Clarke (2006) 6-step approach. Thematic analysis is one of the most commonly used qualitative methods aimed at identifying patterns in the data (*themes*) (Braun and Clarke, 2006; Bryman, 2012b). First, we became familiarized with the data through reading the transcripts multiple

¹⁷ A sample size of 12 interviews is considered as sufficient to reach data saturation in a relatively homogeneous population (Guest, Bunce and Johnson, 2006).

times and taking notes of initial ideas. Secondly, the entire dataset was analysed in a systematic way, grouping pertinent characteristics of the data into codes. Next, the generated codes were clustered into potential themes. Afterwards, the initial generated themes were reviewed considering their consistency and representativeness across the dataset as well as their relevance for our research goals. The last steps involved defining and naming the themes, followed by selecting illustrative interview excerpts¹⁸ for each theme.

7.4. THEMATIC ANALYSIS

Four major themes were developed. The first theme discusses the major impacts of COVID-19 on *GIRA* users, namely the perceived infection risk as well as the impact of government restrictions, particularly mandatory home/teleworking, on their travel behaviour. The following two themes explore the factors that influence bike sharing adoption, specifically the perceived benefits of using the system as well as the main factors behind its success or failure. The last theme delves on the relationship of bike sharing with other modes, particularly with the personal bicycle and the private car. Table 34 provides an overview of the themes and subthemes generated as well as their prevalence.

Table 34 – Themes and subthemes resulting from the thematic analysis as well as the number of times each subtheme was mentioned

Theme	Subtheme	Frequency
COVID-19 effect	<i>Teleworking</i>	20
	<i>Infection risk</i>	31
	<i>Using GIRA to avoid PT</i>	13
	<i>Food delivery couriers</i>	4
Perceived benefits	<i>Reductions in travel times</i>	25
	<i>Reductions in travel costs</i>	12
	<i>Pleasure of cycling</i>	11
	<i>Health benefits</i>	10
	<i>Environmental benefits</i>	9
Success determinants	<i>System coverage</i>	29
	<i>Reliability</i>	37
	<i>E-bikes</i>	26
	<i>Safety</i>	42
Relationship with other modes	<i>Bike sharing & the personal bicycle</i>	23
	<i>Bike sharing & the private car</i>	55

7.4.1. COVID-19 EFFECTS

The first theme discusses the major perceived impacts of COVID-19 on the usage of *GIRA*, being divided into four subthemes. Figure 43 presents the associated subthemes as well as the interviewees that addressed each one of the subthemes.

¹⁸ The interview excerpts presented throughout this study were translated from Portuguese to English by the first author.

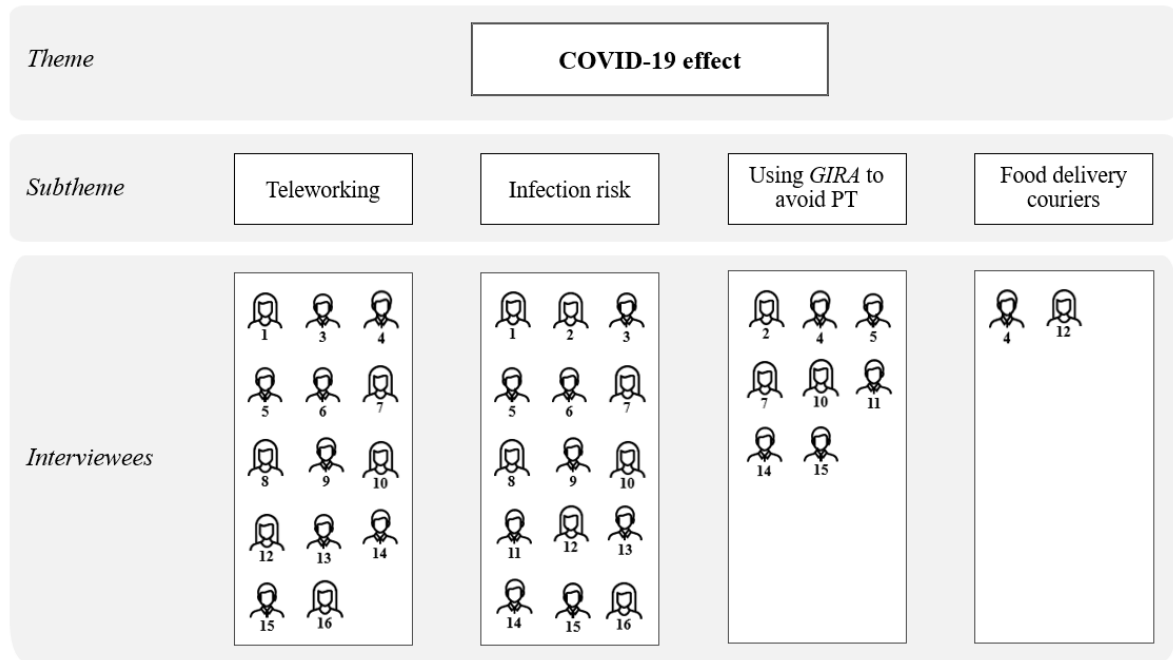


Figure 43 – The COVID-19 effect and the interviewees that mentioned each of its associated subthemes

7.4.1.1. TELEWORKING

The restrictions on travelling implemented to try to curve the spread of the pandemic, limiting mobility especially during the lockdown periods, led to massive reductions on travel demand and, subsequently, also affected *GIRA* usage. As such, most interviewees reported a decrease on *GIRA* usage (as well as on virtually all other modes), particularly during the lockdown phases when teleworking was mandatory as bike sharing was often their mode of transport for commuting:

“The pandemic what it did was that part of my work became remote. So that made me decrease the use of GIRA substantially simply because I didn't have to commute to my work which was the main use of the bicycles. So, I used it less. This was mainly in the first wave...”

(Interviewee 5)

With the gradual lifting of the travel restrictions, users returned to the system. Furthermore, even during the lockdown periods, where *GIRA* ridership generally declined, five interviewees report that they still used the system in the trips that they had to do:

“Anyway, I remember that during the lockdown I had to travel a few times to work and from work. I had some visits and meetings outside and I remember to renew it especially, so I have the annual [GIRA] pass, and I remember at the height of the pandemic of needing to renew [the pass], because it had expired, for using”.

(Interviewee 3)

7.4.1.2. INFECTION RISK

The prevalent opinion among the interviewees was that *GIRA* was a safe mode of transport to be used during the pandemic regarding infection risks, particularly when comparing to PT. Interviewees emphasized *GIRA*'s ability of allowing to maintain a social distance during their trips and to be an outdoor activity, in contrast with PT characterized by having a large number of people together in a closed and poorly ventilated environment. The only precaution mentioned by the interviewees when using *GIRA* was to wash or disinfect their hands before and after use, with some also disinfecting the shared bicycle before using it or wearing a mask during the trip:

"...because we maintain a social distance much more easily, we are in a ventilated area [outdoor]. The only caution is that we are sharing some equipment. If we have this precaution, and we wash or disinfect our hands after using it, I think it is much safer than actually being on a bus or on the subway where social distancing is sometimes not easy, and the fact that it is a very enclosed place."

(Interviewee 3)

"So, if the bicycle was available and if I could use it, I didn't feel that it represented a risk, I mean, before using it I disinfected my hands, after using it I disinfected my hands, so no. Even while cycling I used a mask, even because at the time it was mandatory to wear a mask on the street, so I didn't honestly feel that this represented a risk."

(Interviewee 14)

7.4.1.3. USING GIRA TO AVOID PT

As a consequence of perceiving a lower infection risk while using *GIRA* comparatively to public transport, eight interviewees stated that they prefer to use *GIRA* instead of PT during this pandemic, replacing trips that they had previously done with PT:

"But I really feel that while before it was automatic for me to think about the route I had to take by metro and bus, now I have a previous step which is: "where am I going?" the first thing I do is to open GIRA's app and see where I have stations [...]. And then to try to coordinate walking a little bit, catching a GIRA and, therefore, I have the feeling that it has moved to the top of my mobility resource list, so to speak."

(Interviewee 7)

In fact, two of the interviewees reported to have actually joined *GIRA* during the pandemic in order to avoid using PT:

"... and GIRA was precisely the better mean of transport for avoiding buses, avoiding the subway. At the time it was an important thing to me, yes."

(Interviewee 2)

"Basically, I used to travel by public transport, namely by subway, in Lisbon, and that's it, given the situation I preferred and found it more comfortable to come by bicycle."

(Interviewee 11)

7.4.1.4. FOOD DELIVERY COURIERS

An interesting topic that emerged during the interviews was the fact of *GIRA* being used by food-delivery couriers, such as Uber Eats, during the pandemic and how that impacted the availability of shared bicycles for the users. Two interviewees were extremely against this usage by what they consider an abuse of the system by private companies:

“But GIRA was intensely used by food-delivery couriers, intensely... Indeed, there are all those images of GIRA bicycles always with those backpacks from Bolt and Uber Eats and so on. Meanwhile this has already decreased a little but it's still the same thing, in a place like Bairro de Alvalade [a major Lisbon neighbourhood] where I live, at lunchtime or at dinnertime it's unthinkable to be able to find a GIRA because they're all taken by couriers and, therefore, one of the negative elements is that we are subsidizing something for an absolutely private use in a profit logic.”

(Interviewee 4)

“At lunchtime, for example, the use of GIRA by Uber Eats and the like, which I know is prohibited but, greatly harms people who want to use GIRA during lunchtime and there is no supervision. They use it a lot at that hour and end up harming those who want to travel at lunchtime.”

(Interviewee 12)

In fact, during the first lockdown after a short period where *GIRA* was closed, on March 21st 2020 the system was reopened to support, amongst others, food-delivery couriers as during the lockdowns restaurants and other food services were only allowed to operate through takeaway. However, with the end of the first lockdown in May 2020 and following major backlash from *GIRA* users, including an opinion piece published by a prominent newspaper columnist (Tavares, 2020), the operator decided to end this exceptional measure, but *GIRA* users still complain that this misuse continues to occur.

7.4.2. PERCEIVED BENEFITS

The second theme delves on the perceived benefits of using *GIRA*, aimed at better understanding why interviewees chose to use bike sharing. Users reported several personal benefits with five topics standing out (Figure 44).

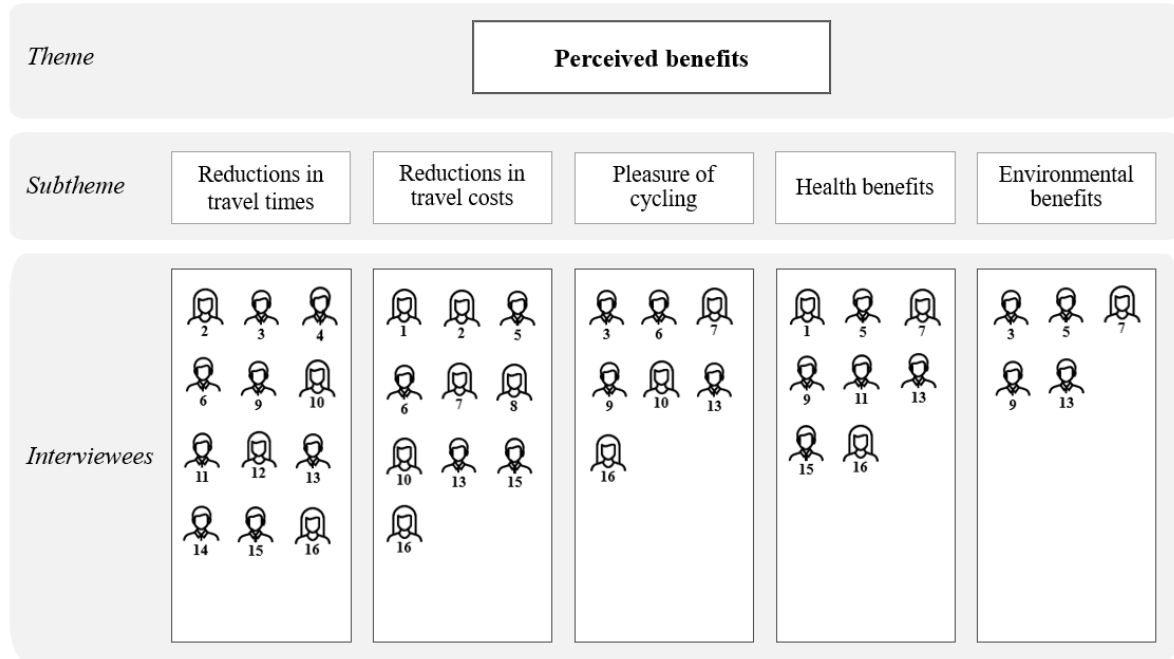


Figure 44 – The Perceived benefits and the interviewees that mentioned each of its associated subthemes

7.4.2.1. REDUCTIONS IN TRAVEL TIMES

Reductions in travel times was the most frequently mentioned benefit, with nine interviewees reporting *GIRA* to be the fastest mode of transport available to them in Lisbon:

“I even had the example that I could get from home to the workplace in 7 minutes [by bicycle]. If it was by walking it would be 20 min, if it was by subway it would also be 20 min, if it was by car it would be half an hour. That’s it, that’s the difference, isn’t it? It turned out to be the most functional mean.”
 (Interviewee 4)

Using *GIRA* allows its users to avoid traffic jams as well as PT strikes and other disruptions that affect those modes:

*“... we are not conditioned by car traffic issues, by public transport strikes that are frequent, by any issue that happens to the bus or metro that makes them stop. So, the next one that only comes after half an hour and a half an hour of transport delay means, maybe, we arrive an hour late to work, and riding a *GIRA* or a bike in general we are usually not so exposed to these issues.”*
 (Interviewee 11)

The existence of segregated cycling lanes is also often associated with decreasing travel times by allowing *GIRA* users to avoid traffic:

“... then with the fact that we have cycling lanes which end up making travelling faster, avoiding road traffic. So, we already have cycling lanes and they are dedicated cycling paths, so it ends up being faster to move to certain places.”

(Interviewee 15)

7.4.2.2. REDUCTIONS IN TRAVEL COSTS

Another *GIRA* feature very appreciated by the users is its affordability, particularly the annual pass which only costs 25 €, leading interviewees to consider *GIRA* to be the cheapest mode of transport available to them:

“And then it has to do with the costs, I think it's much cheaper than using any other type of transport, that's why.”

(Interviewee 15)

7.4.2.3. PLEASURE OF CYCLING

The enjoyment of cycling was also highly regarded by *GIRA* users, with riding a bicycle being considered a much more pleasant activity than driving or using PT:

“... at the end of a working day, it's much more pleasant to take a bike and go somewhere than to get on a bus, taking the subway it's even worse, ...”

(Interviewee 10)

7.4.2.4. HEALTH BENEFITS

GIRA users also valued the opportunity of exercising while travelling as well as the health benefits of cycling, including regarding their mental health. Interviewee 11 perfectly explains this view:

*“In terms of health, it has an excellent effect, it is preferable to cycle, whether with *GIRA* or not, than to take public transport. We have the issue of physical health; we also have the issue of mental health. I notice that those who cycle, those who ride a bicycle usually have a greater decompression in relation to work stress, etc., I think this is also a very important factor nowadays. There is a different contact between, I think, us and the city and the environment that surrounds us, than, for example, travelling in a closed tunnel using the subway, I don't know. I think it's healthier in every way.”*

(Interviewee 11)

7.4.2.5. ENVIRONMENTAL BENEFITS

The environmental benefits of using *GIRA* were also mentioned several times by the interviewees as a reason for joining the system:

“First of all, the environmental theme. I am generally in favour of public transport as a method to reduce CO₂ emissions and unnecessary energy wastes.”

(Interviewee 5)

In particular, interviewees consider bike sharing as a much more environmentally friendly mode of transport than the car:

“Then it's a matter of the concept of a city in which cars must naturally be replaced by means of transport that are less polluting, less invasive, less noisy, ...”

(Interviewee 7)

7.4.3. SUCCESS DETERMINANTS

Although the previous discussed benefits are important motivations for joining and using *GIRA*, they are not enough by themselves to ensure the success of a BSS. Consequently, this theme addresses the structural factors that influence the competitiveness of *GIRA* as a mode of transport. These factors were often characterized by the interviewees as both motivators as well as major barriers affecting their BSS usage. Four factors were identified (Figure 45).

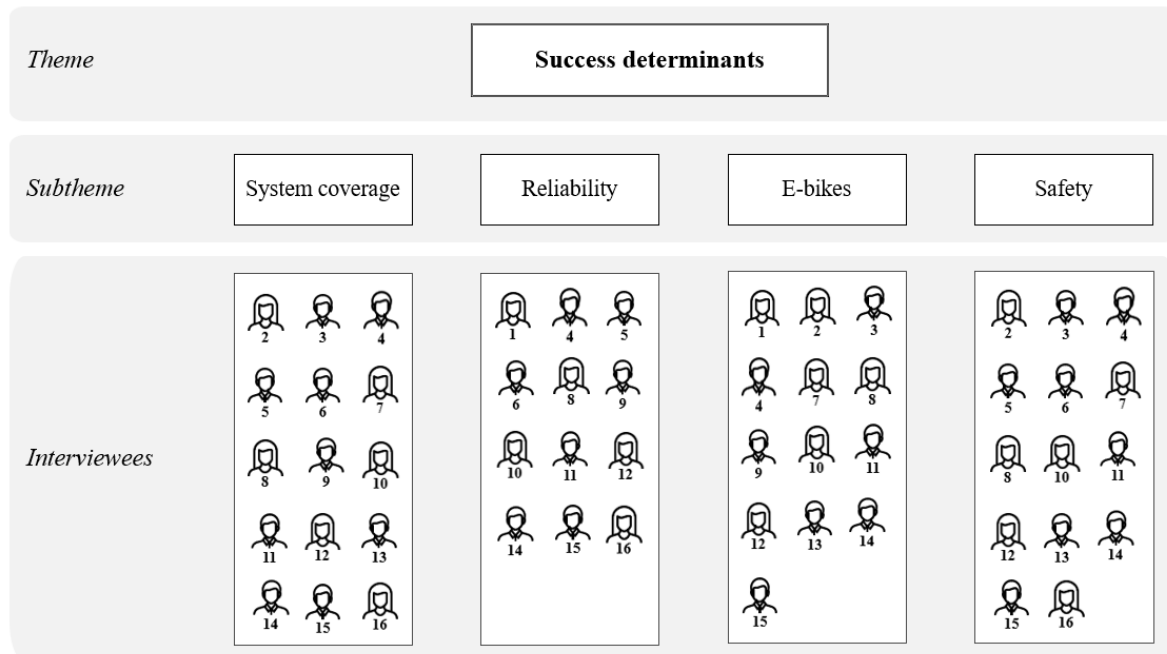


Figure 45 – The *Success determinants* and the interviewees that mentioned each of its associated subthemes

7.4.3.1. SYSTEM COVERAGE

In order to be considered as a viable transport alternative, a BSS needs to sufficiently cover the major destinations of its users. Furthermore, the suitable location of *GIRA* stations directly influences travel times and, consequently, the competitiveness of *GIRA* against other modes of transport:

“Most of my trips are relatively short, I live and work in the city centre, I have ... [GIRA] stations near my home and my workplace, literally 50 m, 100 m from the front door. The place where I do sports, my children's schools, all have [GIRA] stations, all are in the city centre and, therefore, everything has a GIRA nearby ...”

(Interviewee 6)

Therefore, when *GIRA* stations are not sufficiently near their destinations, *GIRA* stops being a transport option. Accordingly, one of the major barriers of *GIRA* mentioned by 15 of the 16 interviewees is that it still doesn't cover enough of Lisbon to always fulfil their travel needs. A better system coverage would allow *GIRA* users to rely more on the system and to replace additional trips currently conducted by other modes of transport, including the car:

"But it's because the GIRA network is not completed, I think that if they completed it [...], it would allow me to make 80% of my trips with GIRA, maybe 80% is too much, but 60%, 70% of the trips."

(Interviewee 13)

This was particularly felt by some interviewees who moved to a new residence still inside Lisbon, but that found themselves now living in areas not served by *GIRA*, forcing them to use other transport alternatives that they wanted to avoid. This is illustrated by interviewee 10 which had avoided using PT during the pandemic due to infection fears but having moved to a new home and confronted with the need to get back to the workplace, had no other option but to use PT:

"...from the moment I got back to the office, I had to use PT again because, there it is, I don't have any [GIRA station] near my home or near the office. Because if not, I even live quite close to my work, I would like to use GIRA for this trip as well."

(Interviewee 10)

7.4.3.2. RELIABILITY

The reliability of the system itself is another major factor that will determine BSS success as a mode of transport. A lack of sufficient available bikes, and to a lesser extend a lack of free docks at the end of the trip, particularly during the rush hours greatly affects the image of the system. Not knowing if a shared bicycle will be available when needed, particularly in their commuting trips which tend to be very time sensitive, leads the users to not trust *GIRA* for their daily travel needs. Eight interviewees reported heavily decreasing their *GIRA* usage due to this fact, leading *GIRA* to become their secondary mode of transport:

"..., it is not a predictability scenario. In other words, I can't think: "I'm going to leave here at a certain time and I'll find a bike available at the station and I'll be able to get to the station where there is a slot available for me to dock the bike". So, this availability of GIRA ended, preventing me from being able to use it in my daily life..."

(Interviewee 4)

Interestingly, two interviewees reported to increase their usage of *GIRA* during the height of the pandemic because it was easier to find shared bicycles available, but with the easing of the travel restrictions, the shortage of bikes returned:

"During the pandemic I was normally working at home, a lot of remote working, and the few times I had to travel, I was able to use GIRA regularly, so I avoided using mine [personal bicycle], and during that period I could use GIRA more easily. With the pandemic over, we are back at the same problem."

(Interviewee 9)

In addition to the lack of bicycles, although in a much smaller scale, interviewees also reported problems with the *app* especially during the process of unlocking the shared bicycle, which made it more difficult to use the system:

"Lately I notice some difficulties in the app. It has happened to me quite recently in two days in a row to unlock the bike, it doesn't unlock, then it won't let me unlock because it says I've unlocked it, I have to call customer support, ..."

(Interviewee 11)

7.4.3.3. E-BIKES

A success feature of *GIRA* is the availability of shared e-bikes which are highly appreciated by the users as it helps them overcome the hilliness of the city and, consequently, the physical effort as well as the worry of arriving sweaty to the workplace:

"... and of course, the electric bikes are also a big motivation because Lisbon is the city of the 7 hills and I'm a smoker and I don't have the lungs to climb hills with a manual bike, especially a GIRA that must weight 20 kg or something."

(Interviewee 7)

Therefore, the shared e-bikes are intensely sought after leading to shortages on availability, which is identified as a problem by users:

"... the few bikes that were there were rarely electric, and I have some more complicated areas on my route and I don't like to arrive at work sweaty, tired, and, therefore, I started to not trust GIRA..."

(Interviewee 9)

7.4.3.4. SAFETY

Safety concerns were also mentioned by 14 of the 16 interviewees as an issue, with a general view that Lisbon is still not a safe place to cycle, particularly for inexperienced cyclists. For instance, Interviewee 6 justify still driving his children to school because he still doesn't feel safe in letting them cycle in the city:

"But then again, there is another factor that I don't weigh a lot for myself, but I do for my children, which is the safety of cycling in the city. In other words, I would say that what would mainly make me [replace his car trips with GIRA] is the safety, because I feel that it's still unsafe to cycle in the city, especially for those who don't have much experience."

(Interviewee 6)

During the pandemic, Interviewee 4 describes that cycling in Lisbon has become more unsafe, not because of the risk of infection, but due to an increase on risky behaviour from car drivers:

“Safe in terms of infection [using GIRA]. In terms of traffic [safety] no, because I think that one of the bad things the pandemic brought was an increase in car speeds. [...] and one of the things that the pandemic provoked was also an epidemic of disregarding red lights. As there were fewer cars in circulation, the few cars that circulated behaved as if they were travelling on a deserted road without any care for anything or anyone, disrespecting signs.”

(Interviewee 4)

In that sense, the existence of segregated cycling lanes was highly regarded by users as increasing safety, including the new pop-up cycling lanes constructed during COVID-19, as they separate cyclists from the motorized traffic. An extension of the cycling network to other parts of the city would also potentially increase cycling usage, as *GIRA* users would feel safer in cycling to additional destinations:

“The other advantage for me is the cycling network that in my route mostly has a cycling lane that is separated from the road. [...] there is a border between the bike path and the road and that for the route that I take is an advantage. Eventually I could use GIRA for other trips if there were cycling lanes available in those routes or if, in some cases, they already exist but I don't consider them safe.”

(Interviewee 14)

Lastly, another issue related to safety is the conditions of the *GIRA* bicycles themselves, with five interviewees reporting that it was common to find shared bicycles in poor conditions, including with faulty brakes, which posed a threat for the user and is blamed on vandalism, bad behaviour of some users, as well as a lack of maintenance and oversight from the operator:

“... the GIRA bikes are very badly, very poorly preserved, because there are abusive behaviours from the users, [...] and, therefore, this even makes me often not feeling safe in a GIRA because the brakes fail, the lights are broken, the basket was used by someone who was sitting there and therefore you can't store things... I see GIRA users in my front and I notice that the wheels are completely bent.”

(Interviewee 4)

7.4.4. RELATIONSHIP WITH OTHER MODES

In addition to the relationship between *GIRA* and PT during the pandemic, which was previously explored in subsection 7.4.1.3., BSS was found to have a complex relationship with two other modes: personal bicycles as well as the private car (Figure 46).

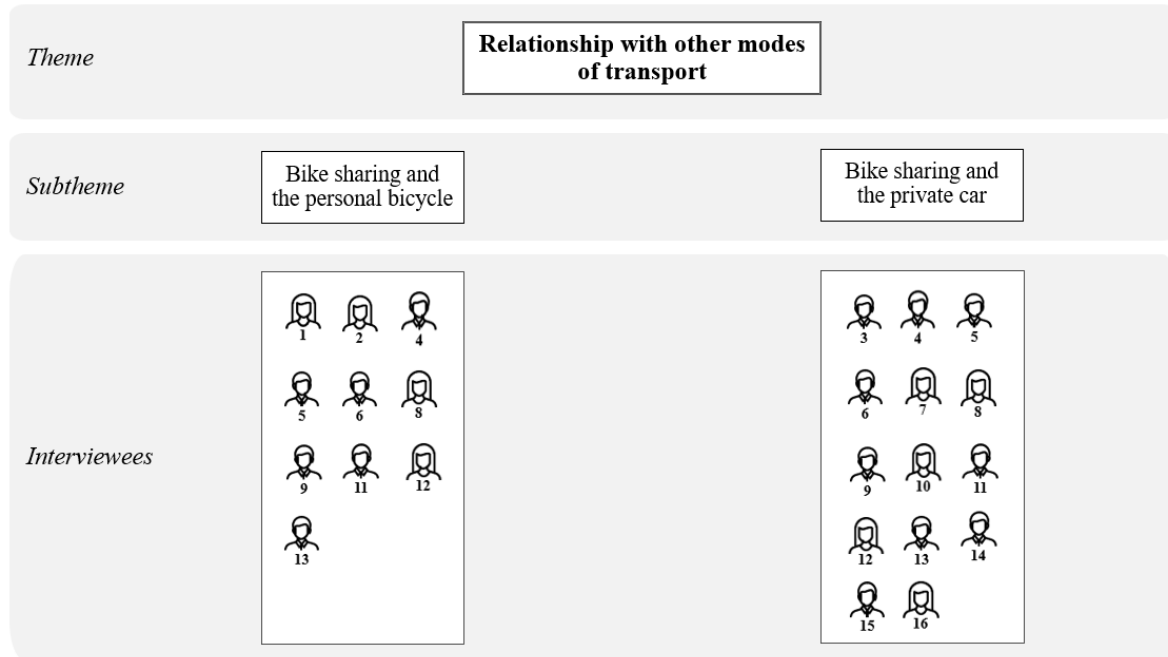


Figure 46 – The *Relationship with other modes of transport* and the interviewees that mentioned each of its associated subthemes

7.4.4.1. BIKE SHARING & THE PERSONAL BICYCLE

GIRA users reported an interesting relationship with personal bicycles. Firstly, interviewees mentioned various advantages that shared bicycles provide comparatively to using a personal bicycle. Specifically, the freedom of not having to worry about where to park or store the bicycle as well as avoiding the maintenance associated with a personal bicycle were highly regarded by four interviewees:

“...we don't need to worry about storing, parking, leaving the bike in a safe place, putting a padlock. So, all these worries associated with using your own bike don't apply because, there, it's a safe shared system, a person leaves it at the dock and goes about their business and doesn't have to worry about where they left their bike, whether it's in a safe place or not, ...”

(Interviewee 2)

Interestingly, four interviewees reported to have their own bicycles but to still prefer to use *GIRA* in certain trips. Firstly, one of the reasons was theft concerns, particularly among those who own e-bikes which they were extra careful where to park them. Secondly, some users prefer *GIRA* because their bicycle is not electric and a shared e-bike decreases the physical effort of their trips. Lastly, users value the flexibility that a shared bicycle provides comparatively to a personal bicycle, giving them the option of cycling in just a part of the trip or in just a part of the day whenever it is more convenient to them:

*“For example, if I have a meeting at the end of the day outside my office, which is 6 km away from home, but it is in a place that is 15 or 20 km away, it makes no sense for me to cycle, so what I do is: I know that in the morning I have to come to the office and so I use *GIRA* and then I'm no longer stuck with the bicycle... so then I can use another mode of transport, like Uber for example, or even another *GIRA*”*

bike, but I don't need to worry about leaving my bicycle parked on the street for a night outside the office. It's really a matter of flexibility."

(Interviewee 11)

At the same time, GIRA has induced new users to take up cycling, with interviewees not only stating that they started cycling due to the system but that they have also bought their own bicycle as a consequence:

"I now have my own bike, but I didn't cycle in the city and I even was one of those people who thought that Lisbon wasn't a city for bicycles and that this huge station I had at my doorstep was an exaggeration because nobody was going to use it. But then I decided to give it a try and it was super quick to get to work. [...] Therefore, I'm one of those people who cycles in the city because of GIRA."

(Interviewee 12)

This role of GIRA in normalizing cycling in Lisbon is well exemplified by Interviewee 13:

"... the permeability of the [GIRA] network in the urban fabric is important and I think it's important also for starting to change the mentality and habits of the people of Lisbon. I mean, if we have GIRA bikes all over the city, anywhere, going from one place to another, the taxi drivers themselves, who are the worst, and the others too, will start to accept that it is part of the norms to have bicycles on the streets like it was back in the 60s or 70s."

(Interviewee 13)

7.4.4.2. BIKE SHARING & THE PRIVATE CAR

Most interviewees report to have their own car but to prefer using GIRA for several reasons, most of them already previously discussed, such as reductions in travel times and costs, cycling being more pleasant than driving as well as environmental benefits. Interviewees describe the act of driving in Lisbon as a costly and a stressful event, filled with traffic jams and difficulties in finding available parking in contrast with the convenience of using GIRA and the enjoyment of cycling:

"In relation to the car, I would say the comfort, I feel much better riding a bicycle than a car, and not having to worry where to park the car and the cost too, it's much cheaper. GIRA is practically, GIRA is free, isn't it?"

(Interviewee 6)

The interviews also revealed that eight participants still use their car in Lisbon. In addition to using their car for long-distance trips outside Lisbon, the interviewees report two major reasons on why they still drive in the city and not replace those trips by GIRA. The first reason was already previously discussed and relates to the fact that GIRA still doesn't cover all of the city (subsection 7.4.3.1.), which hinders the system's ability of meeting all travel needs of its users. The second reason relates to the fact that GIRA is rarely an option when the users need to transport people or cargo. For example, some interviewees reported using their car to transport their family, including more elderly family members, during the pandemic:

“...when I used the car during the pandemic [...] it was more to help other people and to ensure that their transport was safer than if they had to take the bus or the subway, which is the case with my grandmother who uses public transport a lot, so, we tried to avoid that as much as possible [...] Because if it's just for me, GIRA is an excellent option, but sometimes, when it's necessary to guarantee the transport of someone else, GIRA is no longer an option.”

(Interviewee 7)

Users particularly complained about *GIRA*'s inability to be an option for transporting children, with even the inclusion of the newest bicycles' models that can support a child's seat not being a convenient option:

“Even those new GIRA bikes which have that rack for a children's seat, that's not practical, isn't it? [...] first, I have to pick up one of the new GIRA bikes, then I have to have a children's seat that fits on that rack and then I have to carry the children's seat with me when I get to my destination, right? So, I don't think it's practical.”

(Interviewee 12)

Interviewees also recounted conflicts with car drivers, including aggressive driving behaviours from car users towards *GIRA* users and cyclists:

“The main disadvantage, which is changing, it's a matter of culture and habits, which is that the people from Lisbon were very aggressive towards cyclists in the beginning, [especially] the drivers. [...] I had altercations several times, several times I had car drivers suddenly braking to see if I would crash. Anyway, I had all of these confrontations.”

(Interviewee 13)

This issue is part of a bigger challenge regarding the sharing of public space, where car drivers feel threatened by the loss of road space to other purposes leading to conflicts and opposition to cycling promotion. In fact, Lisbon has seen the issue of repurposing car space to cycling taking front stage in this year's municipal elections.

7.5. DISCUSSION

Following mobility trends registered across the world in all modes of transport, the coronavirus has provoked a decrease on *GIRA* usage during the lockdowns due to a reduction on travel demand resulting from mobility restrictions such as mandatory teleworking. However, with the lockdown easing, users returned to the system as they perceived bike sharing to have a low infection risk. In fact, interviewees considered bike sharing to have a lower infection risk comparatively to PT, being an outdoor activity where social distancing was easily maintained in contrast with the overcrowded and closed environment associated with PT. Consequently, participants preferred to use bike sharing instead of PT during the COVID-19 pandemic, with some users joining *GIRA* specifically to avoid using PT. Furthermore, even during the lockdown periods, with stay-at-home policies in full effect, interviewees still used *GIRA* to conduct their essential trips. As such, BSS have a valuable contribution to the resilience of transport systems by providing its users with a transport alternative perceived to have a low infection risk, ensuring their mobility needs during a disruptive event. This is especially important to the more

vulnerable groups, as bike sharing provides an affordable transport alternative. For example, in Lisbon *GIRA* was intensely used by food-delivery couriers particularly during the COVID-19 lockdowns, providing a transport option to a group characterized by their precarious working conditions (Hauben, Lenaerts and Kraatz, 2020) but whose services were in high demand during the pandemic.

At the same time, this study provides evidence on the benefits perceived by BSS users. These include not only tangible benefits such as reductions in travels times and costs, but more intangible ones like the pleasure of cycling or its perceived positive effect on mental health, contrasting with the stressful experiences of using other transport options such as PT or the private car. The positive effects on mental health and subjective well-being associated to cycling are of particular importance during the present pandemic as they can help ameliorate some of the COVID-19 negative effects on mental health such as increases in social isolation and boredom (De Vos, 2020; Brodeur *et al.*, 2021).

Moreover, the analysis uncovered four major factors that influence the competitiveness of BSS. Ensuring that the BSS covers a sufficient portion of the city and that there is a good distribution of shared bicycles across the stations is paramount for its users to be able to rely on the system for their travel needs and will have direct influence on the travel time competitiveness of bike sharing. Likewise, shared e-bikes were highly regarded by users, with this study providing further support for the deployment of e-bike sharing systems, particularly in hilly (or perceived as hilly) cities. Lastly, we found perceived dangerous traffic conditions to be a major barrier for BSS use, particularly for more inexperienced cyclists, with some evidence that this feeling of unsafety has increased during the pandemic due to a surge on risky driving behaviour. In that sense, the provision of segregated cycling lanes was found to be an important motivation for BSS users improving not only their perceived safety but also potentially reducing travel times by allowing users to avoid motorized traffic. The existence of segregated cycling lanes to foster BSS usage is supported by the bicycle counts conducted by Félix, Cambra and Moura (2020) in Lisbon, which found that areas where BSS stations were available but segregated cycling lanes were not cycling levels did not changed (conversely, when both infrastructures were available a significant increase in cycling usage was registered).

Additionally, this research provides evidence on the relationship between bike sharing and the personal bicycle. BSS is considered to be more convenient and more flexible than a personal bicycle, allowing its users to avoid the risk of theft as well as the inconveniences of maintaining, storing and parking a bicycle. Concurrently, BSS also plays an important role in increasing and normalizing cycling by introducing new users to cycling who otherwise wouldn't cycle if the BSS did not exist. In that sense, bike sharing seems to act as a *gateway drug* for cycling, introducing new people to urban cycling, which in turn will later buy and use their own bicycles. Bike counts support the role of *GIRA* in increasing cycling numbers in Lisbon, with counts conducted between 2016 and 2018 showing an 817% increase in cycling levels, with 34% of all trips being conducted with shared bicycles (Félix, Cambra and Moura, 2020).

Lastly, the study also found evidence on the BSS ability of ameliorating car use. Even though most users reported to have a car available to them, they still prefer to use *GIRA* in several of their trips. Using BSS is associated with a pleasant experience that has environmental benefits and allows travel time and cost savings, while using the car in Lisbon is associated with a stressful and expensive activity due to traffic jams and difficulties in parking. *GIRA* users still drive in Lisbon mostly because *GIRA* does not cover all of the city and because bike sharing is an inadequate option for transporting goods (such as groceries) and other people (particularly children).

7.6. CONCLUSIONS AND POLICY RECOMMENDATIONS

With PT facing the risk of a permanent ridership decrease under the scenario where COVID-19 continues to impact mobility, our research provides evidence on the BSS potential of acting as a possible alternative. In this study, we looked at the performance of Lisbon's BSS during the present pandemic using a qualitative approach to shed light on the attitudes of its users. Our research uncovered that bike sharing is not only considered as having a low infection risk, especially comparatively to PT, but also as a travel time and cost competitive mode of transport that provides environmental and health benefits.

Consequently, policymakers should take advantage of bike sharing as an alternative mode, particularly to PT, during disruptive public health emergencies such as the present coronavirus pandemic. In that sense, BSS should not only be allowed to operate during COVID-19 (although with new safety measures implemented such as enhanced cleaning protocols) but used to reinforce transport systems namely through deploying additional stations and bicycles near PT stations and hospitals. Likewise, policymakers could turn to bike sharing as a possible transport option for essential workers during COVID-19 namely through subsidizing programmes providing waivers and free trips.

Moreover, our study provides further evidence on the potential role of bike sharing on normalizing cycling usage in low-cycling settings. Our participants stated not only to start cycling due to bike sharing but also to buy their own personal bicycles as a result. Consequently, by increasing both the number and diversity of cyclists, bike sharing can help to create the political conditions necessary for further investments in cycling as argued by Koglin and Mukhtar-Landgren (2021). Such pressure could induce a reallocation of car space to cycling infrastructure (e.g., converting car lanes into cycling lanes and car parking spaces into BSS stations), challenging the dominant car-dependent environments that characterize most of our cities and, thus, helping to foster a transition from automobility to velomobility.

Our findings about the structural factors affecting the performance of bike sharing as well as regarding its relationship with other modes of transport provide guidance for the formulation of policies for improving the competitiveness of BSS. Based on the results of the interviews, we developed the following set of recommendations for operators and policymakers aimed at maximizing the effectiveness of bike sharing as an alternative mode of transport during COVID-19 and beyond:

- Operators must ensure that BSS covers enough of the city (with special attention to the major trip generators) to allow users to rely on the system for most of their trips.
- The inclusion of shared e-bikes may increase the attractiveness of BSS as they solve some of the main barriers of cycling namely physical effort and transpiration.
- The deployment of BSS should be complemented by the implementation of segregated cycling lanes as it would improve the perceived safety of cycling, which in turn might increase BSS usage rates, fostering the creation of bicycle friendly territories.
- More attention should be given to BSS rebalancing problems. The promotion of mixed land-uses within the catchment areas of BSS could be particularly effective at solving rebalancing issues as it would minimize directional commuting peak flows.
- The concept of seamless travel should always be present when designing bike sharing systems, namely ensuring that the *app* usage is the smoothest experience possible. In that sense, operators could also consider other ways of accessing BSS, namely through integrating the service with PT smartcards.
- Pilot-projects introducing cargo bikes as well as bikes with child seats (respectively, at the BSS stations near supermarkets and preschools) should be tested as such bikes may increase the ability of BSS to carry cargo and children.

- Instead of completely banning food delivery couriers from using bike sharing, BSS operators may consider establishing partnerships, namely through sponsorship deals, with food delivery companies. This would not only provide BSS with additional funding for further expansions but would also increase the sustainability of food delivery services and help to normalize cycling in the city.

Even though the above recommendations were developed based on the feedback from Lisbon's BSS users, the issues faced by *GIRA* are common to several other BSS in the world, particularly docked systems. Future research should continue to analyse the potential of BSS (and other types of micro-mobility such as e-scooter sharing) in increasing the resilience of transport systems, particularly under the scenario where COVID-19 remains a threat and PT systems continue to experience lower ridership levels due to infection fears. Additional studies on how to increase the competitiveness of bike sharing against the car are specially needed as BSS can help to ameliorate a surge in car use during COVID-19 due to a loss of confidence on PT.

8.

CONCLUSIONS

8.1. ANSWERING THE RESEARCH QUESTIONS

RQ1

What are the main benefits of BSS?

The literature review on the BSS impacts (Chapter 2) has revealed several benefits of bike sharing linked to sustainability: **1)** environment, by reducing emissions of GHG and other air pollutants; **2)** health, by increasing PA levels; **3)** equity, by providing an affordable and flexible transport alternative; and **4)** economic, through reducing travel times and congestion, supporting local businesses and increasing housing prices. Crucially, the literature review and the semi-structured interviews (Chapter 7) revealed that BSS can boost cycling levels by providing shared bikes and by increasing the diversity of cyclists and awareness towards cycling.

However, a significant share of the main benefits of BSS are dependent on bike sharing replacing car trips. But current research reveals modest car replacing rates, with most substituted trips coming from sustainable modes of transport (mainly walking and PT). Nevertheless, replacing other modes can still produce benefits, with modal shift from walking to BSS associated with time saving benefits and from PT with reductions in overcrowding levels.

Lastly yet importantly, this study found evidence that bike sharing has an important benefit, which has been broadly overlook so far: **increasing the resilience of urban transport systems during disruptive events** like COVID-19 by providing a transport alternative to the most affected modes (like PT). Several findings support this. First, the literature review on COVID-19 and bike sharing (Chapter 3) found that BSS sustained lower ridership drops and registered faster recoveries comparatively to other modes, particularly PT. Second, both in the travel survey (Chapter 4) and semi-structured interviews (Chapter 7), users considered *GIRA* to be safer to use during COVID-19 than PT, with similar results observed in other case-studies (Chapter 3). Third, the importance of motivations connected with using BSS to avoid PT and for social distancing has significantly increased, with some users specifically joining *GIRA* to avoid having to use PT during the pandemic. Additionally, both the empirical studies and the literature review point to a modal shift from PT to BSS during COVID-19, with findings also suggesting that BSS have minimized a surge in car use by preventing some PT users from shifting to the private car.

RQ2

How has COVID-19 affected the travel behaviour of BSS users?

The coronavirus has provoked a decrease on BSS usage during lockdowns due to a reduction on travel demand resulting from mobility restrictions. However, after restrictions were lifted, BSS usage quickly

recovered and users returned as they perceived bike sharing to have a low infection risk, particularly when compared with PT. Furthermore, the COVID-19 impacts diverged between BSS users. While some users have decreased or stopped using BSS because of COVID-19, others have actually increased usage or joined BSS during the pandemic, resorting to bike sharing to conduct their essential trips.

COVID-19 has also impacted the purpose of BSS trips, with a reduction in commuting and an increase in leisure trips, particularly during lockdowns. In the travel survey (Chapter 4), users reported a decline in the share of *GIRA*'s commuting trips, with most of the users who quitted the system due to COVID-19 using *GIRA* mainly for commuting. Such behaviour was also reported by most interviewees (Chapter 7), which decreased their *GIRA* usage during the lockdowns when teleworking was mandatory. The literature review findings (Chapter 3) further support the increase in the leisure-oriented nature of BSS during coronavirus: **1)** BSS trips conducted during non-working days less affected than those conducted during weekdays; **2)** increase in the number of round-trips; **3)** decline in the two-peak (morning and evening) daily commuting pattern that characterized BSS trips before COVID-19; **4)** increase in the share of BSS trips near residential and outdoor areas; and **5)** increase in the share of casual users.

Significant changes in the relationship of BSS with other modes of transport have been found as well, with COVID-19 accentuating the relationship of competitiveness between BSS and PT. First, the survey has found a decline in the share of multimodal trips combining *GIRA* and PT (Chapter 4), which has also been observed in other studies (Chapter 3). Second, *GIRA* has surpassed PT to become the main mode in commuting trips by its users, with the literature review (Chapter 3) finding BSS to have overall sustained lower ridership drops and faster recoveries than PT. Third, the survey has identified changes in the modal shift dynamics of BSS and PT, with users who would previously replace PT with *GIRA* now replacing other modes, pointing to some users no longer considering PT a viable transport alternative due to the coronavirus. This is further supported by bike sharing being perceived to have a lower infection risk than PT, with users choosing BSS during COVID-19 to avoid PT.

RQ3

What are the most important motivations for using bike sharing before and during COVID-19?

This research has established that the most influential motivations regarding BSS usage both before and during COVID-19 are connected to the *Service Coverage & Quality* (Chapter 5) of bike sharing, particularly the proximity of BSS stations to the users' destinations and the availability of shared e-bikes. The existence of cycling lanes was also identified as an important motivation, with the semi-structured interviews (Chapter 7) revealing that cycling lanes not only improve the perceived safety of BSS usage but are also associated with reducing travel times by allowing users to avoid motorized traffic. The motivations connected to environmental and health gains as well as to the pleasure of cycling (represented by the *Personal Interests & Well-being* motivational factor) were also deemed highly influential on the decision to use bike sharing both pre- and peri-pandemic. In particular, the pleasure of cycling was found to have a similar level of importance as the motivations with the highest scores connect with the *Service Coverage & Quality*.

Above all, this research has found that COVID-19 has provoked a significant increase in the importance of using BSS to avoid PT and for social distancing (represented by the motivational factor *Social Discomfort*). These motivations are now only less influential than the motivations connected to the *Service Coverage & Quality* (i.e., existence of BSS near users' homes and destinations, easiness of using the system, availability of shared e-bikes and existence of cycling lanes).

RQ3.1

How do the motivations for using BSS differ across users replacing different modes of transport before and during COVID-19?

This study has uncovered that most motivations for using BSS are the same regardless of the mode of transport replaced. However, there are some important differences. Both before and during COVID-19, travel costs reductions were particularly important to users replacing car trips, with interviewees describing driving in Lisbon as a costly and stressful event, contrasting with the convenience and enjoyment of using *GIRA*. Moreover, before COVID-19, travel time savings were more associated with users replacing PT or walking than with users replacing car trips. However, during COVID-19 this difference has disappeared, with travel time savings increasing in importance for car users. Lastly, during COVID-19, shared e-bikes were more valued by users replacing PT or walking, while using *GIRA* to access PT was found to be more important to users shifting from private motor vehicles.

Additionally, this study provides evidence on the reasons for using a shared bicycle instead of a personal one. BSS is considered to be more flexible and convenient, allowing to avoid the risk of theft as well as the inconveniences of maintaining, storing and parking a bicycle, with users particularly fond of being able to use BSS in the part of their journey most convenient for cycling.

RQ4

How to capitalize the potential of BSS to contribute to the sustainability and resilience of urban transport systems?

The literature review (Chapter 2) has established that the bulk of the citywide benefits of implementing a BSS are contingent on its ability to replace car trips (specifically, decreases in GHG and other air pollutants, increases in PA, time savings and congestion reductions). As such, the clearest path to increase the contribution of bike sharing to sustainable mobility is by enhancing its attractiveness to car users. In that sense, this research offers insights on how to increase BSS car replacement rates:

1. It was revealed that one of the factors important for users shifting from private motor vehicles were reductions in travel costs (Chapter 6). Additionally, motivations such as the suitable location of BSS stations near destinations and the pleasure of cycling were found to be important to all BSS users regardless of the replaced modes.
2. The semi-structured interviews (Chapter 7) allowed the identification of four structural factors that influence the competitiveness of BSS as a mode of transport (system coverage, reliability, e-bikes, and safety), with the insufficient coverage of *GIRA* particularly hindering the ability of users to stop driving in Lisbon. The inadequacy of BSS to transport other people and goods was also identified as a major disadvantage against the car.
3. The provision of segregated cycling lanes was found to be an important motivator for BSS users, improving not only their perceived safety but also their travel times. While at same time, bike sharing was associated with attracting new cyclists. Thus, implementing segregated cycling lanes alongside BSS could increase the overall competitiveness of cycling against the car.

Lastly, this study has established that BSS have played a key role during the coronavirus pandemic by increasing the resilience of urban transport systems to disruptive public health crises. As previously stated, comparatively to PT, bike sharing is perceived as safer (with an increase in importance of using BSS to avoid PT and to maintain a social distance) and its ridership was less affected. In that sense, improving the capability of bike sharing to function as an alternative mode during these types of

disruptive events provides an important pathway to increase its contribution to the resilience of transport systems.

8.2. ADDRESSING THE RESEARCH GOAL

By heavily affecting PT, one of the best sustainable alternatives to private car usage, COVID-19 can potentially provoke a further increase in car travel, exacerbating its negative impacts, including on climate change. At the same time, especially during the height of the pandemic, citizens (particularly essential workers) needed safe modes of transport for their essential mobility needs. However, infections fears and restrictions on PT impacted the transport systems' ability of ensuring the mobility needs of citizens, particularly affecting the most vulnerable groups (including essential workers such as food retail workers), which were most in need for transport alternatives besides PT but didn't had access to a car.

In that sense, bike sharing systems offered a valuable third option both to PT and to the car during this pandemic. As such, bike sharing has the potential to increase the sustainability and resilience of urban transport systems during disruptive public health crises like COVID-19 by:

- Mitigating a modal shift from PT to the private car, not only by directly shifting PT users to BSS who would otherwise choose the car, but also by reducing PT overcrowding levels for the remaining PT passengers (potentially avoiding further shifts to the car)
- Providing an additional transport alternative for fulfilling essential mobility needs (with users considering bike sharing to be convenient, sustainable and affordable) where a social distance can be kept

8.3. POLICY RECOMMENDATIONS

Policy insights can be derived from this thesis regarding the implementation and promotion of bike sharing systems, particularly during disruptive public health crises like the coronavirus pandemic.

First, this thesis has found evidence on the importance of BSS as a viable transport alternative during COVID-19, not only providing the population with an affordable and sustainable mode of transport where social distancing can be maintained but also mitigating a modal shift from PT to the private car. As such, policymakers should not only allow BSS to operate during these types of infectious public health crises, but also take advantage of the bike sharing's capability to act as an alternative mode, particularly to PT. Systems that provide e-bikes (found to be amongst the most valued motivations by users) could be especially capable of acting as an alternative due to the increased range of e-bikes. A possible strategy could, thus, entail deploying additional BSS stations and shared bicycles (for instance, during the reopening phases) near major trip generators (such as healthcare facilities and other destinations with higher demand during the pandemic) to reduce the pressure from PT services. Concurrently, BSS operators could promote bike sharing as a mode of transport capable of ensuring a safe social distance, while at the same time implementing measures to reduce the infection risk such as enhancing cleaning procedures and avoiding agglomerations of users.

Second, this research has contributed to the identification of the major factors that influence the competitiveness of bike sharing as a mode of transport in urban areas. Four main factors were established:

1. **System coverage:** policymakers and operators must ensure that bike sharing covers a sufficient portion of the city (with special attention to the major trip generators) to allow users to rely on BSS for their travel needs.
2. **Reliability:** not knowing if a shared bicycle (and to a less extend a free dock to leave the bicycle) will be available when needed, leads users to not trust BSS for their daily travel needs. In that sense, more attention should be given to BSS rebalancing problems. For example, docked systems could introduce more flexible approaches such as allowing during rush hour users to leave the shared bicycles near the stations but without the need of locking the bike in a dock (*geofencing*). The promotion of mixed land-uses within the catchment areas of BSS could be particularly effective at solving rebalancing issues as it would minimize directional commuting peak flows.
3. **E-bikes:** Users highly regarded shared e-bikes, with this study providing further support for the deployment of e-bike sharing systems, particularly in hilly cities as they solve some of the main barriers of cycling namely physical effort and transpiration.
4. **Safety:** the implementation of BSS must be accompanied by measures aimed at increasing the safety of using bike sharing, which now involves two different dimensions. On the one hand, traffic safety as perceived dangerous traffic conditions were identified as a major barrier for BSS use, particularly for more inexperienced cyclists, which should be minimized by the provision of segregated cycling lanes. On the other hand, the risk of infection posed by coronavirus (as the perceived safety of using *GIRA* has declined), where the transmission risk from contaminated surfaces or from gatherings near the BSS stations should be reduced.

Third, as already mentioned in the previous subsection, this research provides additional insights on how to potentiate the car replacement capability of bike sharing. Marketing campaigns advertising the advantages of riding a shared bicycle in contrast with the disadvantages of the car (e.g., the pleasure of cycling versus being stuck in traffic jams) may be particularly effective in attracting new car drivers. Similarly, introducing shared cargo bikes as well as bikes with child seats (for instance, near supermarkets and preschools) could also increase the attractiveness of bike sharing to car drivers as the inadequacy of BSS to transport other people (especially children) and carrying goods was also identified as a major disadvantage against the car. Furthermore, BSS operators could particularly take advantage of the travel cost savings' importance to car users by marketing the potential savings of a modal shift to BSS (e.g., by presenting the potential monthly or annual savings of switching from a car to BSS). Concurrently, policymakers may consider increasing the cost of car usage, (e.g., through increasing car parking charges in the catchment areas of BSS stations) to induce further car modal shift to BSS.

Additionally, several motivations, such as the suitable location of BSS stations near the users' destinations, the existence of e-bikes as well as the pleasure of cycling and the associated environmental and health benefits, were found to be important to all BSS users both before and during COVID-19. Consequently, operators should consider these universal features when designing their marketing campaigns for promoting BSS usage.

Finally, this research provides further support for the deployment of BSS in conjunction with the implementation of segregated cycling lanes as it would improve the perceived safety of cycling (and potentially reduce travel times), which in turn might increase BSS usage rates. Such synergies could create a virtuous cycle where segregated cycling lanes foster the conditions for BSS use and an increase in BSS ridership fuels the pressure for additional cycling investment. This, in turn, may help to foment the necessary political conditions for shifting car space to cycling, consequently, supporting the creation of bicycle friendly territories and decreasing car utility.

8.4. LIMITATIONS AND FUTURE RESEARCH

Concerning the limitations of this thesis, the analyses relied on self-reported behaviours, which may in some circumstances not reflect actual behaviour. Another limitation is related to the survey distribution (convenience sampling), prone to the risk of selection bias, which can potentially lead to an overrepresentation of respondents more easily accessible and more willing to participate. The initial aim was to reach all of *GIRA*'s users with a valid email on the operator's database (in order to use *GIRA*, users need to provide a valid email account) which would ensure that all respondents had the same probability of being selected. However, after months of negotiations it was not possible to obtain the authorization from the operator to disseminate the survey through its database. Nevertheless, this shortcoming was addressed by disseminating the survey in several online channels and by comparing the obtained sample with a representative survey previously conducted by *GIRA*'s operator.

Furthermore, the comparison between the periods before and during COVID-19 relied on retrospective questions, which are susceptible to recall biases. However, the severity and disruptive nature of COVID-19, makes it realistic to assume that respondents still remembered their pre-pandemic behaviour at the time of the survey. The survey was also conducted during the beginning of the second COVID-19 wave and, as such, the behaviour of BSS users may have been different from, for instance, conducting the survey during the peak of a COVID-19 wave or a period with low infection rates. In that sense, longitudinal data obtained by employing multiple survey waves throughout the different phases of the pandemic could have produced a better account of the COVID-19 impacts on bike sharing. However, the time limitations associated with a PhD thesis coupled with the lack of support from *GIRA*'s operator restricted such methodological approach. Nevertheless, the semi-structured interviews conducted a year after the survey delivered additional details on the behaviour changes of BSS users throughout the different phases of the COVID-19 pandemic.

It is acknowledged that more complex statistical methods could have been employed, such as structural equations models (SEM) to describe the relative effect of the various motivations on the groups of *GIRA* users. Likewise, nested logit models could have been used to analyse the motivations of users replacing different modes of transport (which would allow, for instance, to compare potential differences between users replacing different PT modes such as the train, metro and the bus). However, the application of such models was restricted by the modest sizes of the obtained sample. Nonetheless, the employed statistical methods have allowed the identification of important insights that complement the current state of knowledge, namely by showing the increase on the importance of using BSS to avoid PT and for social distancing. Moreover, the application of both quantitative and qualitative methods has provided a more complete picture regarding the impacts of COVID-19 on the behaviour of BSS users, which would not have been obtained by applying either approach alone.

Lastly, the findings from this thesis (and subsequent policy recommendations) are mainly based on insights from the BSS users of Lisbon, a Western European compact, mixed-use and dense starter cycling city with high accessibility levels and the centre of a metropolitan territory. As such, the results of this study may not be directly transferable to other territorial contexts.

In that regard, future research should explore the role of bike sharing in different territorial contexts besides city cores. For instance, the increase on teleworking as a result of COVID-19 could exacerbate urban sprawl as workers may now choose to live further away from their workplace (de Abreu e Silva, 2022), potentially disrupting pre-pandemic directional commuting patterns from the periphery to the city centres. Concurrently, the coronavirus pandemic has led to a new appreciation for the existence of amenities at the local level near residential locations, leading to a renewed prominence of local accessibility and the need for proximity to essential activities (e.g., "15-minute city") (Moreno *et al.*,

2021; Silva and Altieri, 2022). In that sense, BSS (as well as cycling and other shared micro-mobility like e-scooter sharing systems) could potentially be an important transport option for short local trips in those territories, where PT may struggle to be competitive due to lower densities.

Furthermore, future studies should continue to focus on the potential contribution of bike sharing towards increasing the resilience and sustainability of transport systems, especially during disruptive events. In here, studies should not only continue to investigate the resilience of BSS during public health crises similar to the coronavirus pandemic, but also expand to other types of emergencies such as extreme weather events which are expected to increase in frequency and magnitude as a result of climate change (Stott, 2016; Carbon Brief, 2022). Accordingly, assessing the capability of BSS to act as a substitute to PT (research conducted during PT disruptions, such as strikes and maintenance operations, could produce important insights) and to the car (with studies on how to increase the competitiveness of BSS against the car, including through synergies with other policies such as cycling lanes, especially needed) should constitute research priorities.

9.

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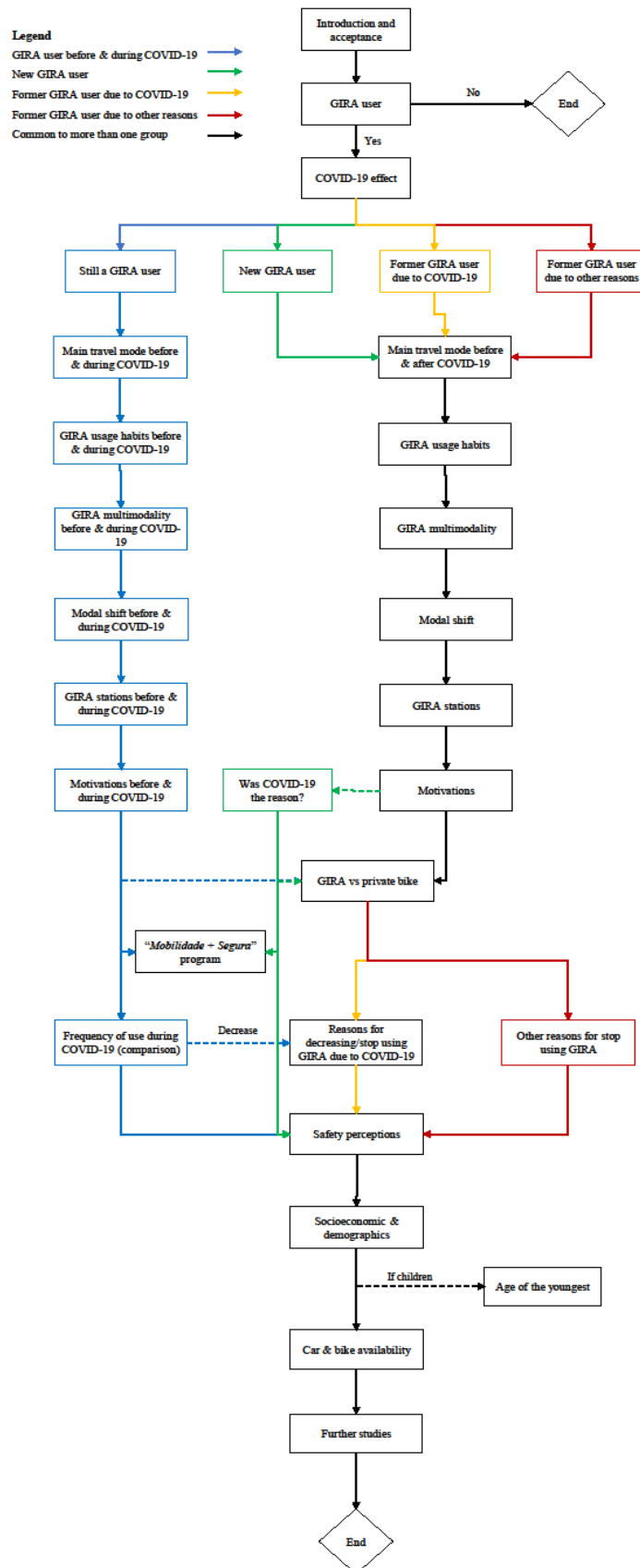
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10.

APPENDICES

A1. SURVEY STRUCTURE



A2. SURVEY IN PORTUGUESE

Inquérito aos utilizadores da GIRA

Descrição e Objetivos

O presente inquérito enquadra-se na investigação de doutoramento do estudante João Teixeira do Programa Doutoral em Planeamento do Território da Faculdade de Engenharia da Universidade do Porto e destina-se aos utilizadores do sistema de bicicletas partilhadas de Lisboa intitulado GIRA.

Tem como objetivo analisar os padrões de mobilidade e as motivações dos utilizadores do sistema GIRA, visando obter uma melhor compreensão dos perfis de utilizadores deste tipo de sistemas.

Impacto do Atual Contexto Pandémico

Devido às consequências da pandemia COVID-19 este inquérito terá uma componente de avaliação da COVID-19 nos padrões de utilização da GIRA. Desta forma, ao longo do inquérito iremos solicitar em determinadas questões que compare as suas rotinas diárias atuais nesta fase de desconfinamento com um momento da sua vida em que a pandemia não afetava as suas rotinas diárias (por exemplo, os primeiros dois meses de 2020).

Todas as questões são de resposta fechada. O tempo estimado para o preenchimento do inquérito é de 10 minutos.

RGPD e Proteção de Dados Pessoais

Os dados recolhidos neste inquérito não permitirão identificá-lo diretamente e serão utilizados exclusivamente para fins académicos, sendo acedidos apenas pelo responsável do estudo. Não existirá transferência de dados para entidades terceiras. Os resultados deste estudo poderão ser divulgados de forma agregada em conferências, publicações em revistas ou outros meios de comunicação científicos.

No final do Inquérito poderá fornecer-nos o seu contacto de e-mail, caso tenha interesse em participar noutras fases deste estudo. Se nos fornecer esse contacto, ele será conservado separadamente das respostas ao inquérito e utilizado apenas para o informar sobre essas fases, convidando à sua participação.

A qualquer momento poderá solicitar a retificação ou a eliminação do seu contacto, junto do investigador (email: ega11021@fe.up.pt (<mailto:ega11021@fe.up.pt>)).

Para dúvidas ou questões relacionadas com o estudo pode contactar ega11021@fe.up.pt (<mailto:ega11021@fe.up.pt>). Quaisquer dúvidas relacionadas especificamente com a proteção dos seus dados pessoais podem ser endereçadas a dpo@reit.up.pt (<mailto:dpo@reit.up.pt>).

Se aceitar participar neste estudo, de acordo com as condições descritas acima, por favor prossiga com o preenchimento do inquérito.

Agradecemos desde já a sua colaboração que é fundamental para esta investigação.

There are 56 questions in this survey.

Adesão à GIRA

Utiliza ou alguma vez utilizou o sistema de bicicletas partilhadas GIRA? *

Por favor, seleccione apenas uma das seguintes opções:

- ☐ Sim
☐ Não

Efeito da COVID-19

Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA: *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente
- ☐ Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade
- ☐ Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19
- ☐ Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19

Efeito da COVID-19

Ao longo das seguintes questões pedimos-lhe que compare as suas rotinas diárias **ANTES DA PANDEMIA COVID-19** com as suas rotinas **NA FASE ATUAL DE DESCONFINAMENTO** (sugerimos, por exemplo, que compare o momento atual com as suas rotinas nos primeiros dois meses de 2020).

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Hábitos de Mobilidade Gerais

Na seguinte questão pedimos-lhe que compare as suas rotinas diárias **ANTES DA PANDEMIA COVID-19** com as suas rotinas **NA FASE ATUAL DE DESCONFINAMENTO** (sugerimos, por exemplo, que compare o momento atual com as suas rotinas nos primeiros dois meses de 2020).

Qual o modo de transporte ou combinação de modos que normalmente utilizava nas suas deslocações entre casa e o local de trabalho/estudo **ANTES DA PANDEMIA COVID-19**?

Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada.

No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.

*

Por favor, selecione todas as que se aplicam:

- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Barco
- ☐ Bicicleta própria
- ☐ Bicicleta GIRA
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

O modo de transporte ou combinação de modos que utiliza nas suas deslocações entre casa e o local de trabalho/estudo **NA FASE ATUAL DE DESCONFINAMENTO** é o mesmo que utilizava **ANTES DA PANDEMIA COVID-19**?

*

Por favor, selecione apenas uma das seguintes opções:

- ☐ Sim, continuo a utilizar o(s) mesmo(s) modo(s) de transporte
- ☐ Não, atualmente utilizo um modo de transporte diferente
- ☐ Deixei de realizar a viagem entre casa e o local de trabalho/estudo

Qual o modo de transporte ou combinação de modos que normalmente utiliza nas suas deslocações entre casa e o local de trabalho/estudo **NA FASE ATUAL DE DESCONFINAMENTO**?

Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada.

No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Não, atualmente utilizo um modo de transporte diferente' na pergunta '5 [Q3A]' (O modo de transporte ou combinação de modos que utiliza nas suas deslocações entre casa e o local de trabalho/estudo **NA FASE ATUAL DE DESCONFINAMENTO** é o mesmo que utilizava **ANTES DA PANDEMIA COVID-19?**)

Por favor, selecione **todas** as que se aplicam:

- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Barco
- ☐ Bicicleta própria
- ☐ Bicicleta GIRA
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Hábitos de Utilização da GIRA

Esta secção tem como propósito avaliar os seus hábitos de utilização da GIRA.

Com que frequência utiliza a GIRA?

Indique a sua frequência de utilização da GIRA ANTES DA PANDEMIA COVID-19 e NA FASE ATUAL DE DESCONFINAMENTO.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione a posição apropriada para cada elemento:

	Antes da pandemia COVID-19	Na fase atual de Desconfinamento
Mais de 10 vezes por semana	☐	☐
5 a 10 vezes por semana	☐	☐
3 a 4 vezes por semana	☐	☐
1 a 2 vezes por semana	☐	☐
Menos de 1 vez por semana	☐	☐
Menos de 1 vez por mês	☐	☐

Com que frequência utiliza ou utilizava a GIRA? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Mais de 10 vezes por semana
- ☐ 5 a 10 vezes por semana
- ☐ 3 a 4 vezes por semana
- ☐ 1 a 2 vezes por semana
- ☐ Menos de 1 vez por semana
- ☐ Menos de 1 vez por mês

Qual o tipo de passe GIRA que costuma possuir? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione a posição apropriada para cada elemento:

	Antes da pandemia COVID-19	Na fase atual de Desconfinamento
Passe Anual	☐	☐
Passe Mensal	☐	☐
Passe Diário	☐	☐

Qual o tipo de passe GIRA que costuma ou costumava possuir? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Passe Anual
- ☐ Passe Mensal
- ☐ Passe Diário

Indique o motivo principal das suas viagens quando utiliza a GIRA: *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione a posição apropriada para cada elemento:

	Antes da pandemia COVID-19	Na fase atual de Desconfinamento
Ir para o local de trabalho/estudo	☐	☐
Tratar de assuntos profissionais (por exemplo; ir a uma reunião)	☐	☐
Tratar de assuntos pessoais (por exemplo; ir ao banco, ir a uma consulta, fazer compras, etc.)	☐	☐
Lazer ou turismo	☐	☐
Fazer exercício	☐	☐

Indique o motivo principal das suas viagens quando utiliza ou utilizava a GIRA: *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Ir para o local de trabalho/estudo
☐ Tratar de assuntos profissionais (por exemplo; ir a uma reunião)
☐ Tratar de assuntos pessoais (por exemplo; ir ao banco, ir a uma consulta, fazer compras, etc.)
☐ Lazer ou turismo
☐ Fazer exercício

Dinâmicas Modais Antes da Pandemia COVID-19

Considere a viagem mais frequente que realizava através da GIRA ANTES DA PANDEMIA COVID-19.

Na sua viagem mais frequente com a GIRA que realizava **ANTES DA PANDEMIA COVID-19**, recorria a uma combinação de modos de transporte ou apenas utilizava a GIRA? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta não foi 'Bicicleta GIRA' na pergunta '4 [Q3A1]' (Qual o modo de transporte ou combinação de modos que normalmente utilizava nas suas deslocações entre casa e o local de trabalho/estudo **ANTES DA PANDEMIA COVID-19**? Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada. No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)
- ☐ Apenas a GIRA era utilizada

Nota: Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

Que modo(s) de transporte combinava com a GIRA na sua viagem frequente **ANTES DA PANDEMIA COVID-19**?

Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)' na pergunta '13 [Q7A1]' (Na sua viagem mais frequente com a GIRA que realizava **ANTES DA PANDEMIA COVID-19**, recorria a uma combinação de modos de transporte ou apenas utilizava a GIRA?)

Por favor, selecione todas as que se aplicam:

- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Barco
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Relativamente à viagem mais frequente que realizava através da GIRA ANTES DA PANDEMIA COVID-19, qual o Modo de Transporte que utilizaria caso a GIRA não existisse?

Selecione o modo de transporte que a GIRA substituiu com maior regularidade ANTES DA PANDEMIA COVID-19.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Não realizaria a viagem caso a GIRA não existisse (é uma nova viagem)
- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Bicicleta própria
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)
- ☐ Outro, por favor especifique

Dinâmicas Modais na Fase Atual de Desconfinamento

Considere a viagem mais frequente que realiza através da GIRA NA FASE ATUAL DE DESCONFINAMENTO.

Na sua viagem mais frequente com a GIRA que realiza **NA FASE ATUAL DE DESCONFINAMENTO**, recorre a uma combinação de modos de transporte ou apenas utiliza a GIRA? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

----- Scenario 1 -----

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta não foi 'Bicicleta GIRA' na pergunta '4 [Q3A1]' (Qual o modo de transporte ou combinação de modos que normalmente utilizava nas suas deslocações entre casa e o local de trabalho/estudo ANTES DA PANDEMIA COVID-19? Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada. No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.) e A resposta for 'Sim, continuo a utilizar o(s) mesmo(s) modo(s) de transporte' na pergunta '5 [Q3A]' (O modo de transporte ou combinação de modos que utiliza nas suas deslocações entre casa e o local de trabalho/estudo NA FASE ATUAL DE DESCONFINAMENTO é o mesmo que utilizava ANTES DA PANDEMIA COVID-19?)

----- ou Scenario 2 -----

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta não foi na pergunta '6 [Q3A2]' (Qual o modo de transporte ou combinação de modos que normalmente utiliza nas suas deslocações entre casa e o local de trabalho/estudo NA FASE ATUAL DE DESCONFINAMENTO? Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada. No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.) e A resposta for 'Não, atualmente utilizo um modo de transporte diferente' na pergunta '5 [Q3A]' (O modo de transporte ou combinação de modos que utiliza nas suas deslocações entre casa e o local de trabalho/estudo NA FASE ATUAL DE DESCONFINAMENTO é o mesmo que utilizava ANTES DA PANDEMIA COVID-19?)

----- ou Scenario 3 -----

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta for 'Deixei de realizar a viagem entre casa e o local de trabalho/estudo' na pergunta '5 [Q3A]' (O modo de transporte ou combinação de modos que utiliza nas suas deslocações entre casa e o local de trabalho/estudo NA FASE ATUAL DE DESCONFINAMENTO é o mesmo que utilizava ANTES DA PANDEMIA COVID-19?)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)
- ☐ Apenas a GIRA é utilizada

Nota: Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

Que modo(s) de transporte combina com a GIRA na sua viagem frequente **NA FASE ATUAL DE DESCONFINAMENTO**?

Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)' na pergunta '16 [Q7A2]' (Na sua viagem mais frequente com a GIRA que realiza NA FASE ATUAL DE DESCONFINAMENTO, recorre a uma combinação de modos de transporte ou apenas utiliza a GIRA?)

Por favor, selecione **todas** as que se aplicam:

- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Barco
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Relativamente à viagem mais frequente que realiza através da GIRA **NA FASE ATUAL DE DESCONFINAMENTO**, qual o Modo de Transporte que utilizaria nessa viagem caso a GIRA não existisse?

Selecione o modo de transporte que a GIRA substitui com maior regularidade **NA FASE ATUAL DE DESCONFINAMENTO**.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Não realizaria a viagem caso a GIRA não existisse (é uma nova viagem)
- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Bicicleta própria
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Dinâmicas Modais

Considere a **viagem mais frequente** que realiza ou realizava através da GIRA.

Na sua viagem mais frequente com a GIRA, recorre a uma combinação de modos de transporte ou apenas utiliza a GIRA?

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta não foi 'Bicicleta GIRA' na pergunta '6 [Q3A2]' (Qual o modo de transporte ou combinação de modos que normalmente utiliza nas suas deslocações entre casa e o local de trabalho/estudo NA FASE ATUAL DE DESCONFINAMENTO? Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada. No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.)

Por favor, selecione apenas uma das seguintes opções:

☐ Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)

☐ Apenas a GIRA é utilizada

Nota: Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

Que modo(s) de transporte combina com a GIRA na sua viagem frequente?

Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)' na pergunta '19 [Q7B1]' (Na sua viagem mais frequente com a GIRA, recorre a uma combinação de modos de transporte ou apenas utiliza a GIRA?)

Por favor, selecione todas as que se aplicam:

☐ A pé

☐ Automóvel particular

☐ Autocarro

☐ Barco

☐ Comboio

☐ Elétrico

☐ Metro

☐ Motociclo

☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Na sua viagem mais frequente com a GIRA, recorria a uma combinação de modos de transporte ou apenas utilizava a GIRA?

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA;) e A resposta não foi 'Bicicleta GIRA' na pergunta '4 [Q3A1]' (Qual o modo de transporte ou combinação de modos que normalmente utilizava nas suas deslocações entre casa e o local de trabalho/estudo ANTES DA PANDEMIA COVID-19? Selecione mais do que um modo apenas se utiliza uma combinação de modos de transporte para a mesma viagem (exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida o Metro). Apenas considere viagens "A pé" se estas forem exclusivas ou se representarem mais de 5 minutos seguidos numa viagem combinada. No caso de não trabalhar nem estudar, considere os seus destinos mais frequentes.)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)
- ☐ Apenas a GIRA era utilizada

Nota: Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

Que modo(s) de transporte combinava com a GIRA na sua viagem frequente?

Apenas considere viagens "A pé" se estas representarem mais de 5 minutos seguidos na sua viagem.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Combinação de modos (por exemplo: para chegar ao meu trabalho apanho o Comboio e de seguida a GIRA)' na pergunta '21 [Q7C1]' (Na sua viagem mais frequente com a GIRA, recorria a uma combinação de modos de transporte ou apenas utilizava a GIRA?)

Por favor, selecione todas as que se aplicam:

- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Barco
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)

☐ Outro, por favor especifique:

Relativamente à viagem mais frequente que realiza ou realizava através da GIRA, qual o Modo de Transporte que utilizaria nessa viagem caso a GIRA não existisse?

Selecione o modo de transporte que a GIRA substituiu com maior regularidade.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Não realizaria a viagem caso a GIRA não existisse (é uma nova viagem)
- ☐ A pé
- ☐ Automóvel particular
- ☐ Autocarro
- ☐ Bicicleta própria
- ☐ Comboio
- ☐ Elétrico
- ☐ Metro
- ☐ Motociclo
- ☐ Táxi ou equivalente (por exemplo, UBER)
- ☐ Outro, por favor especifique

Estações GIRA

Pedimos-lhe agora que considere as estações GIRA que utiliza ou utilizava nas suas viagens frequentes com a GIRA. Considere a Origem como o local onde retira a bicicleta GIRA da doca e o Destino como o local em que deixa a bicicleta GIRA na doca. Caso realize a mesma viagem em sentido inverso, refira-se à primeira viagem do dia.

Indique a estação de ORIGEM das suas viagens frequentes com a GIRA ANTES DA PANDEMIA COVID-19:

Selecione a estação ou Indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ 101 - Alameda dos Oceanos / Rua dos Argonautas
- ☐ 102 - Porta do Mar
- ☐ 103 - Jardim da Água
- ☐ 104 - Gare do Oriente
- ☐ 105 - CC Vasco da Gama
- ☐ 106 - Jardim Garcia da Orta
- ☐ 107 - Rotunda dos Vice-Reis
- ☐ 108 - Rua do Bojador
- ☐ 109 - Alameda dos Oceanos / Rua Ilha dos Amores
- ☐ 110 - Rua de Moscavide
- ☐ 112 - Alameda dos Oceanos / Passeio das Garças
- ☐ 114 - Via do Oriente
- ☐ 115 - Passeio dos Heróis do Mar / Rua Capitão Cook
- ☐ 208 - Cais das Pombas
- ☐ 212 - Av. Infante Dom Henrique / Terminal de Cruzeiros
- ☐ 214 - Largo de Santos
- ☐ 215 - Av. 24 de Julho
- ☐ 216 - Praça D. Luís I
- ☐ 218 - Cais do Sodré
- ☐ 219 - Praça do Município
- ☐ 222 - Praça da Figueira
- ☐ 224/225 - Martim Moniz
- ☐ 301 - Avenida da Liberdade / Restauradores
- ☐ 304 - Avenida da Liberdade / São Jorge
- ☐ 305 - Avenida da Liberdade / Rua Barata Salgueiro
- ☐ 306 - Avenida da Liberdade / Rua Alexandre Herculano
- ☐ 307/308 - Marquês de Pombal
- ☐ 309 - Rua da Palma
- ☐ 401 - Rua Martens Ferrão / Av. Fontes Pereira de Melo
- ☐ 403 - Av. Fontes Pereira de Melo
- ☐ 406/407/408 - Praça Duque de Saldanha
- ☐ 410 - Rua da Mesquita / Universidade Nova de Lisboa
- ☐ 412/413 - Av. Ressano Garcia / Av. António Augusto de Aguiar

- ☐ 414 – Av. Duque de Ávila / Rua Pinheiro Chagas
- ☐ 415 – Av. Duque de Ávila / Av. Conde Valbom
- ☐ 416 – Av. República / Avenida Duque de Ávila
- ☐ 417 – Av. Duque de Ávila / Jardim Arco do Cego
- ☐ 419 – Av. António José de Almeida / Instituto Superior Técnico
- ☐ 420 – Av. Rovisco Pais / Av. Manuel da Maia
- ☐ 421 – Alameda D. Afonso Henriques
- ☐ 423 – Av. Conde Valbom / Rua Marquês Sá da Bandeira
- ☐ 426 – Av. Elias Garcia / Av. 5 de Outubro
- ☐ 427 – Av. República / Av. Visconde Valmor
- ☐ 428 – Av. República / Avenida Barbosa Du Bocage
- ☐ 430 – Av. Barbosa Du Bocage / Rua Arco do Cego
- ☐ 431 – Rua do Arco Cego / Av. Magalhães Lima
- ☐ 432 – Praça de Londres
- ☐ 433 – Av. Paris / Av. Almirante Reis
- ☐ 442 – Campo Pequeno
- ☐ 443 – Av. de Roma / Fórum Lisboa
- ☐ 446 – Av. República / Interface Entrecampos
- ☐ 449 – Av. 5 de Outubro / Rua da Cruz Vermelha
- ☐ 450 – Rua Alfredo Cortês
- ☐ 452 – Rua Teixeira de Pascoais / Rua Dr. Gama Barros
- ☐ 453 – Av. Roma / Av. EUA
- ☐ 456 – Entrecampos / Av. das Forças Armadas
- ☐ 457 – Rua Aboim Ascensão
- ☐ 459 – Rua Maria Amália Vaz de Carvalho / ES Rainha D. Leonor
- ☐ 460 – Av. Rio de Janeiro / Parque de Jogos 1º de Maio
- ☐ 462 – Campo Grande / Biblioteca Nacional
- ☐ 463 – Campo Grande / Av. da Igreja
- ☐ 464 – Av. da Igreja / Rua Afonso Lopes Vieira
- ☐ 468 – Largo Frei Heitor Pinto
- ☐ 471 – Rua Lopes de Mendonça / EB São João de Brito
- ☐ 472 – Rua Marquês Soveral / ES Padre António Vieira
- ☐ 473 – Av. do Brasil / Av. de Roma
- ☐ 474 – Av. do Brasil / Av. Rio de Janeiro
- ☐ 475 – Av. Professor Gama Pinto / Cantina Velha
- ☐ 476 – Av. Professor Gama Pinto / Reitoria
- ☐ 480 – Faculdade de Ciências
- ☐ 481 – Campo Grande / Museu da Cidade
- ☐ 483 – Rua Professor Francisco Lucas Pires
- ☐ 484 – Rua Professor Vieira de Almeida
- ☐ 485 – Rua Tomás da Fonseca / Rua António Albino Machado

- ☐ 486 – Rua Hermano Neves / Rua José Escada
☐ 487 – Rua Professor João Barreira
☐ 488 – Rua Fernando Namora / Rua António Quadros
☐ 490 – Rua Fernando Namora / Azinhaga da Torre do Fato

☐ Ponto de referência

Indique a estação de DESTINO das suas viagens frequentes com a GIRA ANTES DA PANDEMIA COVID-19:

Selecione a estação ou indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

(same list of *GIRA* stations)

As estações GIRA que utiliza NA FASE ATUAL DE DESCONFINAMENTO são as mesmas que utilizava ANTES DA PANDEMIA COVID-19? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Sim, continuo a utilizar as mesmas estações GIRA
☐ Não, as estações GIRA que utilizo são diferentes

Indique a estação de ORIGEM das suas viagens frequentes com a GIRA NA FASE ATUAL DE DESCONFINAMENTO:

Selecione a estação ou indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Não, as estações GIRA que utilizo são diferentes' na pergunta '26 [Q10A]' (As estações GIRA que utiliza NA FASE ATUAL DE DESCONFINAMENTO são as mesmas que utilizava ANTES DA PANDEMIA COVID-19?)

Por favor, selecione apenas uma das seguintes opções:

(same list of *GIRA* stations)

Indique a estação de DESTINO das suas viagens frequentes com a GIRA NA FASE ATUAL DE DESCONFINAMENTO:

Selecione a estação ou Indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:) e A resposta for 'Não, as estações GIRA que utilizo são diferentes' na pergunta '26 [Q10A]' (As estações GIRA que utiliza NA FASE ATUAL DE DESCONFINAMENTO são as mesmas que utilizava ANTES DA PANDEMIA COVID-19?)

Por favor, selecione apenas uma das seguintes opções:

(same list of *GIRA* stations)

Indique a estação de ORIGEM das suas viagens frequentes com a GIRA:

Selecione a estação ou Indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

(same list of *GIRA* stations)

Indique a estação de DESTINO das suas viagens frequentes com a GIRA:

Selecione a estação ou Indique um ponto de referência.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

(same list of *GIRA* stations)

Selecione uma estimativa da distância a que se localiza a estação GIRA mais próxima do seu local de **Residência**: *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Menos de 250 metros (menos de 3 minutos a pé)
- ☐ 250 a 500 metros (3 a 6 minutos a pé)
- ☐ 500 a 1000 metros (6 a 12 minutos a pé)
- ☐ Mais de 1000 metros (mais de 12 minutos a pé)
- ☐ Não sei

Selecione uma estimativa da distância a que se localiza a estação GIRA mais próxima do seu local de **Destino**: *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Menos de 250 metros (menos de 3 minutos a pé)
- ☐ 250 a 500 metros (3 a 6 minutos a pé)
- ☐ 500 a 1000 metros (6 a 12 minutos a pé)
- ☐ Mais de 1000 metros (mais de 12 minutos a pé)
- ☐ Não sei

Motivações

Esta secção visa compreender as suas motivações para a utilização da GIRA.

A razão para a sua recente adesão ao programa GIRA deveu-se às consequências da pandemia COVID-19? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Sim
- ☐ Não

Avalie de 1 a 5 o grau de importância de cada um dos seguintes fatores na sua decisão de utilizar a GIRA. Compare a importância de cada fator **ANTES DA PANDEMIA COVID-19** e **NA FASE ATUAL DE DESCONFINAMENTO**:

Escala: 1 – Nada Importante 2 – Pouco Importante 3 – Algo Importante 4 – Importante 5 – Muito Importante

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta 2 [Q2] (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione a posição apropriada para cada elemento:

	Antes da pandemia COVID-19					Na fase atual de Desconfinamento				
	1	2	3	4	5	1	2	3	4	5
Redução nos meus tempos de viagem	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Redução nos meus custos de transporte	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Maior flexibilidade nas minhas viagens	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Aceder ao Transporte Público (por exemplo, uso a GIRA para aceder ao metro)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Evitar de utilizar o Transporte Público	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Preocupação com o meio ambiente	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Melhorar a minha forma física	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Preocupação com a minha saúde	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Prazer em andar de bicicleta	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A rede de cicloviás servir a minha viagem	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
O tráfego automóvel circular com pouca velocidade no meu trajeto	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existência de estações GIRA junto do meu local de residência	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existência de estações GIRA junto dos meus destinos	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existência de bicicletas elétricas GIRA	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facilidade em utilizar o sistema GIRA	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Influência de pessoas que conheço (familiares, amigos e/ou colegas)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

	Antes da pandemia COVID-19					Na fase atual de Desconfinamento					
	1	2	3	4	5		1	2	3	4	5
Ver outras pessoas na cidade a utilizar bicicletas GIRA no dia a dia	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Campanhas promocionais da GIRA	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Manter o distanciamento social na minha viagem	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐

Avalie de 1 a 5 o grau de importância de cada um dos seguintes fatores na sua decisão de utilizar a GIRA:

Escala: 1 – Nada Importante 2 – Pouco Importante 3 – Algo Importante 4 – Importante 5 – Muito Importante

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' ou 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' ou 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione a posição apropriada para cada elemento:

	1	2	3	4	5
Redução nos meus tempos de viagem	☐	☐	☐	☐	☐
Redução nos meus custos de transporte	☐	☐	☐	☐	☐
Maior flexibilidade nas minhas viagens	☐	☐	☐	☐	☐
Aceder ao Transporte Público (por exemplo, uso a GIRA para aceder ao metro)	☐	☐	☐	☐	☐
Evitar de utilizar o Transporte Público	☐	☐	☐	☐	☐
Preocupação com o meio ambiente	☐	☐	☐	☐	☐
Melhorar a minha forma física	☐	☐	☐	☐	☐
Preocupação com a minha saúde	☐	☐	☐	☐	☐
Prazer em andar de bicicleta	☐	☐	☐	☐	☐
A rede de cicloviás servir a minha viagem	☐	☐	☐	☐	☐
O tráfego automóvel circular com pouca velocidade no meu trajeto	☐	☐	☐	☐	☐
Existência de estações GIRA junto do meu local de residência	☐	☐	☐	☐	☐
Existência de estações GIRA junto dos meus destinos	☐	☐	☐	☐	☐
Existência de bicicletas elétricas GIRA	☐	☐	☐	☐	☐
Facilidade em utilizar o sistema GIRA	☐	☐	☐	☐	☐
Influência de pessoas que conheço (familiares, amigos e/ou colegas)	☐	☐	☐	☐	☐
Ver outras pessoas na cidade a utilizar bicicletas GIRA no dia a dia	☐	☐	☐	☐	☐
Campanhas promocionais da GIRA	☐	☐	☐	☐	☐

	1	2	3	4	5
Manter o distanciamento social na minha viagem	☐	☐	☐	☐	☐

Indique as razões para ter optado por usar uma GIRA em vez de uma bicicleta própria:

Selecione todas as opções que se aplicam.

*

Por favor, selecione todas as que se aplicam:

- ☐ Porque não tenho bicicleta própria
- ☐ Porque é mais barato do que comprar uma bicicleta
- ☐ Para evitar o risco de roubo
- ☐ Porque há falta de locais de estacionamento de bicicletas junto dos meus destinos
- ☐ Porque não tenho onde guardar a minha bicicleta em casa
- ☐ Para evitar problemas de manutenção
- ☐ Porque a minha bicicleta não é elétrica
- ☐ É mais fácil de combinar com o Transporte Público
- ☐ Porque posso usar só numa parte da minha viagem quando me é mais conveniente
- ☐ Outra, por favor especifique:

Aderiu ao programa da GIRA **"Mobilidade + Segura"**?

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' ou 'Aderi à GIRA recentemente já com a pandemia COVID-19 a ser uma realidade' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Sim
- ☐ Não

Nota: Programa de isenção de pagamento da mensalidade GIRA a profissionais de saúde, segurança e proteção civil.

Como descreveria a sua frequência de utilização da GIRA NA FASE ATUAL DE DESCONFINAMENTO comparativamente ao período ANTES DA PANDEMIA COVID-19?

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA antes da pandemia COVID-19 e continuo a utilizar atualmente' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Aumentou
☐ Manteve-se
☐ Diminuiu

Tendo respondido que **diminuiu** a sua frequência de utilização da GIRA NA FASE ATUAL DE DESCONFINAMENTO, quais foram as razões para essa diminuição?

Selecione todas as que se aplicam.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Diminuiu' na pergunta '38 [Q18A]' (Como descreveria a sua frequência de utilização da GIRA NA FASE ATUAL DE DESCONFINAMENTO comparativamente ao período ANTES DA PANDEMIA COVID-19?)

Por favor, selecione todas as que se aplicam:

- ☐ Deixei de realizar a viagem que fazia via GIRA (por exemplo, antes usava a GIRA para ir para o trabalho, mas agora estou em regime de teletrabalho)
☐ Para evitar o risco de contágio
☐ Outra, por favor especifique:

Tendo respondido que **deixou de utilizar** a GIRA como consequência da pandemia, quais foram as razões para essa decisão?

Selecione todas as que se aplicam.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar atualmente como consequência da pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione todas as que se aplicam:

- ☐ Deixei de realizar a viagem que fazia via GIRA (por exemplo, antes usava a GIRA para ir para o trabalho, mas agora estou em regime de teletrabalho)
☐ Para evitar o risco de contágio
☐ Outra, por favor especifique:

Tendo respondido que deixou de utilizar a GIRA por outras razões não relacionadas com a pandemia, quais foram as razões para essa decisão?

Selecione todas as que se aplicam.

*

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Era utilizador da GIRA, mas deixei de utilizar por outra razão não relacionada com a pandemia COVID-19' na pergunta '2 [Q2]' (Escolha a opção que mais se aplica à sua situação atual de utilização da GIRA:)

Por favor, selecione todas as que se aplicam:

- ☐ Custo de utilização elevado
- ☐ O sistema GIRA é difícil de utilizar
- ☐ As bicicletas GIRA encontram-se em mau estado
- ☐ Escassez de bicicletas convencionais GIRA disponíveis
- ☐ Escassez de bicicletas elétricas GIRA disponíveis
- ☐ Escassez de docas disponíveis onde deixar a bicicleta GIRA
- ☐ Escassez de estações junto do meu local de residência
- ☐ Escassez de estações junto dos meus destinos (local de trabalho/estudo ou de interesse)
- ☐ Escassez de ciclovias que sirvam a minha viagem
- ☐ O tráfego automóvel circula com elevada velocidade no meu trajeto
- ☐ Sofri um acidente rodoviário
- ☐ Por motivos de saúde
- ☐ Tive um filho
- ☐ Mudei de cidade
- ☐ Mudei de local de residência
- ☐ Mudei de local de trabalho/estudo
- ☐ Adquiri automóvel próprio
- ☐ Adquiri motociclo próprio
- ☐ Adquiri trotineta própria
- ☐ Passei a utilizar a minha própria bicicleta
- ☐ Passei a utilizar outro sistema de bicicletas partilhadas (JUMP, Hive)
- ☐ Passei a utilizar um sistema de trotinetas partilhadas
- ☐ Passei a utilizar car sharing
- ☐ Outra, por favor especifique:

Avalie de 1 a 5 o quão seguro se sente em utilizar os seguintes modos de transporte em Lisboa. Compare a sua percepção **ANTES DA PANDEMIA COVID-19** e **NA FASE ATUAL DE DESCONFINAMENTO**:

Escala: 1 - Nada Seguro 2 - Pouco Seguro 3 - Algo Seguro 4 - Seguro 5 - Muito Seguro

*

Por favor, selecione a posição apropriada para cada elemento:

	Antes da pandemia COVID-19						Na fase atual de Desconfinamento				
	1	2	3	4	5		1	2	3	4	5
A pé	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Automóvel particular	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Bicicleta própria	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Bicicleta GIRA	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Transportes Públicos	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐

Dados Socioeconómicos e Demográficos

Para terminar...

Reside no concelho de Lisboa? *

Por favor, selecione apenas uma das seguintes opções:

☐ Sim

☐ Não, indique o seu concelho por favor

Por favor selecione a faixa etária em que se encontra: *

Por favor, selecione apenas uma das seguintes opções:

☐ Menos de 18 anos

☐ 18-19 anos

☐ 20-24 anos

☐ 25-29 anos

☐ 30-34 anos

☐ 35-39 anos

☐ 40-44 anos

☐ 45-49 anos

☐ 50-54 anos

☐ 55-59 anos

☐ 60-64 anos

☐ Mais de 64 anos

Género: *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Feminino
- ☐ Masculino
- ☐ Outro

Qual o nível de escolaridade mais elevado que completou? *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Ensino Básico
- ☐ Ensino Secundário
- ☐ Licenciatura ou equivalente
- ☐ Mestrado/Mestrado Integrado/MBA
- ☐ Doutoramento

Qual é a sua situação perante o trabalho? *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Empregado(a) a tempo inteiro
- ☐ Empregado(a) a tempo parcial
- ☐ Estudante
- ☐ Trabalhador(a)-Estudante
- ☐ Reformado(a) ou pré-reformado(a)
- ☐ Desempregado(a) ou outra situação de inatividade

Qual é a capacidade de poupança mensal do seu agregado familiar? *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Menos de 25% do vencimento
- ☐ 25% a 50% do vencimento
- ☐ Mais de 50% do vencimento
- ☐ Não sei / Não respondo

Quantas pessoas constituem o seu agregado familiar, contando consigo? *

Por favor, selecione apenas uma das seguintes opções:

- ☐ 1 (só eu)
- ☐ 2
- ☐ 3 ou mais

Tem filhos ou dependentes menores a seu cargo? *

Por favor, selecione apenas uma das seguintes opções:

- ☐ Sim
- ☐ Não

Qual é a idade do seu filho/dependente mais novo? *

Responda a esta pergunta apenas se as seguintes condições são verdadeiras:

A resposta for 'Sim' na pergunta '50 [Q29]' (Tem filhos ou dependentes menores a seu cargo?)

Por favor, selecione apenas uma das seguintes opções:

- ☐ Menos de 6 anos
- ☐ 7 a 12 anos
- ☐ Mais de 12 anos

Possui carta de condução? *

Por favor, selecione apenas uma das seguintes opções:

- ☐ Sim
- ☐ Não

Possui, ou costuma possuir, passe mensal de Transportes Públicos? *

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Sim
☐ Não

Tem disponível algum automóvel que possa utilizar?

*

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Sim
☐ Não

Por exemplo: Ter automóvel próprio ou poder utilizar um automóvel do seu agregado familiar.

Tem disponível alguma bicicleta que possa utilizar?

*

Por favor, selecione **apenas uma** das seguintes opções:

- ☐ Sim
☐ Não

Por exemplo: Ter bicicleta própria ou poder utilizar uma bicicleta do seu agregado familiar.

Para terminar o inquérito, por favor carregue em "Submeter".

Agradecemos a sua participação.

Estudos Posteriores

Para compreender em maior profundidade as motivações por detrás da escolha de utilizar sistemas de bicicletas partilhadas como a GIRA, esta investigação terá uma segunda componente de recolha de dados prevista para o primeiro trimestre de 2021 que consistirá na realização de grupos focais e/ou entrevistas semiestruturadas.

Caso tenha interesse em participar, por favor, click no seguinte link onde lhe iremos pedir que forneça um email de contacto.

Nota: O contacto de email será utilizado apenas para o informar sobre a segunda fase, convidando à sua participação.

Submeter o seu inquérito

Obrigado por ter concluído este inquérito.

A3. SURVEY QUESTION REGARDING SAFETY PERCEPTIONS

Rate from 1 (Not Safe at All) to 5 (Very Safe) how safe you feel on using the following modes of transport in Lisbon. Compare your perception **Before the COVID-19 Pandemic** and **Now**.

Scale: 1 - not safe at all; 2 - not very safe; 3 - somewhat safe; 4 - safe; 5 - very safe

	Before COVID-19 Pandemic					Now				
	1	2	3	4	5	1	2	3	4	5
WALKING										
PRIVATE CAR										
PERSONAL BICYCLE										
GIRA SHARED BICYCLE										
PUBLIC TRANSPORT										

A4. INTERVIEW PROTOCOL IN PORTUGUESE

TEXTO INTRODUTÓRIO

Caro(a) participante,

Muito obrigado por ter aceitado participar no estudo. Este estudo está a ser realizado no âmbito do meu Doutoramento que tem como objetivo analisar os padrões de mobilidade e as motivações dos utilizadores do sistema de bicicletas partilhadas de Lisboa, a *GIRA*, visando obter uma melhor compreensão dos perfis de utilizadores deste tipo de sistemas.

EM QUE CONSISTIRÁ A SUA PARTICIPAÇÃO

Como referido no email que recebeu, a sua participação consistirá numa pequena conversa onde irei fazer-lhe algumas questões relativas à sua experiência de utilização da *GIRA*, bem como do próprio impacto da pandemia COVID-19 nessa utilização.

A entrevista terá uma curta duração de cerca de 15 minutos e será gravada para facilitar a análise posterior da informação.

Recordo que todas as informações recolhidas serão tratadas de forma confidencial e exclusivamente utilizadas para o propósito deste estudo.

É importante também dizer-lhe que caso queira fazer uma pausa, ou caso não se sinta confortável ou não queira responder a alguma questão em particular que está completamente à vontade para o fazer.

Antes de começarmos a entrevista, tem alguma dúvida relativamente a estas ou outras questões que me queira colocar?

Posto isto, vou dar início à gravação e começar com a entrevista.

GUIÃO DA ENTREVISTA

UTILIZAÇÃO DA GIRA

1. Começo por perguntar se utiliza atualmente a *GIRA*?

VERSÃO UTILIZADOR (SE SIM)

IMPACTO DA COVID-19

1. Já utilizava a *GIRA* antes da atual pandemia ou começou a utilizar durante a pandemia?
2. (Se já utilizava antes da pandemia) O que é que o/a levou a aderir à *GIRA*?
 - Qual foi o impacto da COVID-19 na sua utilização da *GIRA*?
2. (Se aderiu durante a pandemia) O que é que o/a levou a aderir à *GIRA* durante a pandemia?
3. Para além da *GIRA*, quais são os modos de transporte que normalmente utiliza em Lisboa?
 - Qual foi o impacto da COVID-19 na sua utilização desses modos?
4. Durante a pandemia, qual é o modo de transporte que considera mais seguro utilizar?
 - Porquê?
5. Ainda considerando o período durante a pandemia, considera mais seguro utilizar a *GIRA* ou o Transporte Público (como o metro ou o autocarro)?
 - Porquê?

RELAÇÃO COM OUTROS MODOS DE TRANSPORTE

6. Peço-lhe agora que pense nas viagens mais frequentes que realiza com a *GIRA* durante a pandemia. Qual seria o modo de transporte que utilizaria nessas viagens caso a *GIRA* não existisse?
 - O que é que o/a levou a optar por utilizar a *GIRA* em vez desse modo de transporte?
7. Utiliza habitualmente o automóvel particular nas suas viagens?
 - O que é que poderia levar a que substituísse essas, ou parte dessas, viagens pela *GIRA*?
8. Na sua opinião, quais são as principais vantagens da *GIRA*?
 - E as principais desvantagens?

PÓS-PANDEMIA

9. Após a pandemia terminar, tenciona continuar a utilizar a *GIRA*?
 - Porquê?

- (Caso não tencione) O que o/a levaria a continuar a utilizar a *GIRA*?

VERSÃO EX-UTILIZADOR (SE NÃO)

UTILIZAÇÃO DA GIRA

1. Quando era utilizador/a da *GIRA*, o que é que o/a levou a aderir ao sistema?

IMPACTO DA COVID-19

2. Porquê que deixou de utilizar a *GIRA*?

- (Se devido à COVID-19) Tendo respondido que deixou de utilizar a *GIRA* como consequência da pandemia, quais foram as razões para essa decisão? Foi o risco de infeção ou está mais relacionado com, por exemplo, deixar de realizar a viagem que fazia via *GIRA* porque passou a estar em teletrabalho?

3. Qual é o modo de transporte que passou a utilizar nessas viagens que realizava anteriormente com a *GIRA*?

4. Qual foi o impacto da COVID-19 na sua utilização desse modo?

- E na utilização de outros modos que normalmente utiliza em Lisboa?

5. Durante a pandemia, qual é o modo de transporte que considera mais seguro utilizar?

- Porquê?

6. Ainda considerando o período durante a pandemia, considera mais seguro utilizar a *GIRA* ou o Transporte Público (como o metro ou o autocarro)?

- Porquê?

RELAÇÃO COM OUTROS MODOS DE TRANSPORTE

7. Utiliza habitualmente o automóvel particular nas suas viagens?

- O que é que poderia levar a que substituísse essas, ou parte dessas, viagens pela *GIRA*?

8. Na sua opinião, quais são as principais vantagens da *GIRA*?

- E as principais desvantagens?

PÓS-PANDEMIA

9. (Se devido à COVID-19) Após a pandemia terminar, tenciona voltar a utilizar a *GIRA*?

(Se devido a outras razões) Tenciona no futuro voltar a utilizar a *GIRA*?

- Porquê?
- (Caso não tencione) O que o/a levaria a voltar a utilizar a *GIRA*?

DADOS SOCIODEMOGRÁFICOS

Por fim, e apenas para fins estatísticos, vou lhe só colocar duas questões sobre o seu perfil sociodemográfico, em que irei lhe pedir para seleccionar uma opção entre várias.

1. Qual é a sua faixa etária?
 - A. Menos de 18 anos
 - B. 18-24 anos
 - C. 25-34 anos
 - D. 35-44 anos
 - E. 45-54 anos
 - F. 55-64 anos
 - G. Mais de 64 anos

2. Qual é a sua situação perante o trabalho?
 - A. Empregado(a)
 - B. Estudante
 - C. Trabalhador(a)-Estudante
 - D. Reformado(a) ou pré-reformado(a)
 - E. Desempregado(a) ou outra situação de inatividade

TEXTO FINAL

Chegamos ao fim da entrevista.

Muito obrigado pelo seu contributo. Tem alguma questão que gostaria de me colocar?

Caso tenha alguma dúvida futuramente sobre os seus dados ou sobre o estudo pode contactar-me através do email no qual recebeu o convite para esta entrevista.

Desejo-lhe a continuação de um resto de um bom dia.

A5. LIST OF THE INTERVIEW QUESTIONS IN ENGLISH

1. Let me start by asking if you currently use *GIRA*?
2. Did you already use *GIRA* before the current pandemic or did you start using it during the pandemic?
3. What led you to join *GIRA*?
4. What was the impact of COVID-19 on your usage of *GIRA*?
5. Besides *GIRA*, what are the other modes of transport that you normally use in Lisbon?
 - 5.1. What was the impact of COVID-19 on your usage of these modes?
6. During the pandemic, which is the mode of transport that you consider to be the safest to use? And why?
7. Still considering the period during the pandemic, do you consider to be safer to use *GIRA* or Public Transport (such as the metro or bus)? Why?
8. Please think about the most frequent trips you made with *GIRA* during the pandemic. Which mode of transport would you have used if *GIRA* did not exist?
 - 8.1. What led you to choose to use *GIRA* instead of that mode of transport?
9. Do you usually use a private car on your trips?
 - 9.1. [If yes] What could make you replace those, or part of those, trips with *GIRA*?
10. In your opinion, what are the major advantages of *GIRA*?
 - 10.1. And disadvantages?
11. After the pandemic ends, do you intend to continue using *GIRA*? Why?
 - 11.1. [If no] What would drive you to continue using *GIRA*?

A6. ADDITIONAL ANALYSES FROM CHAPTER 3

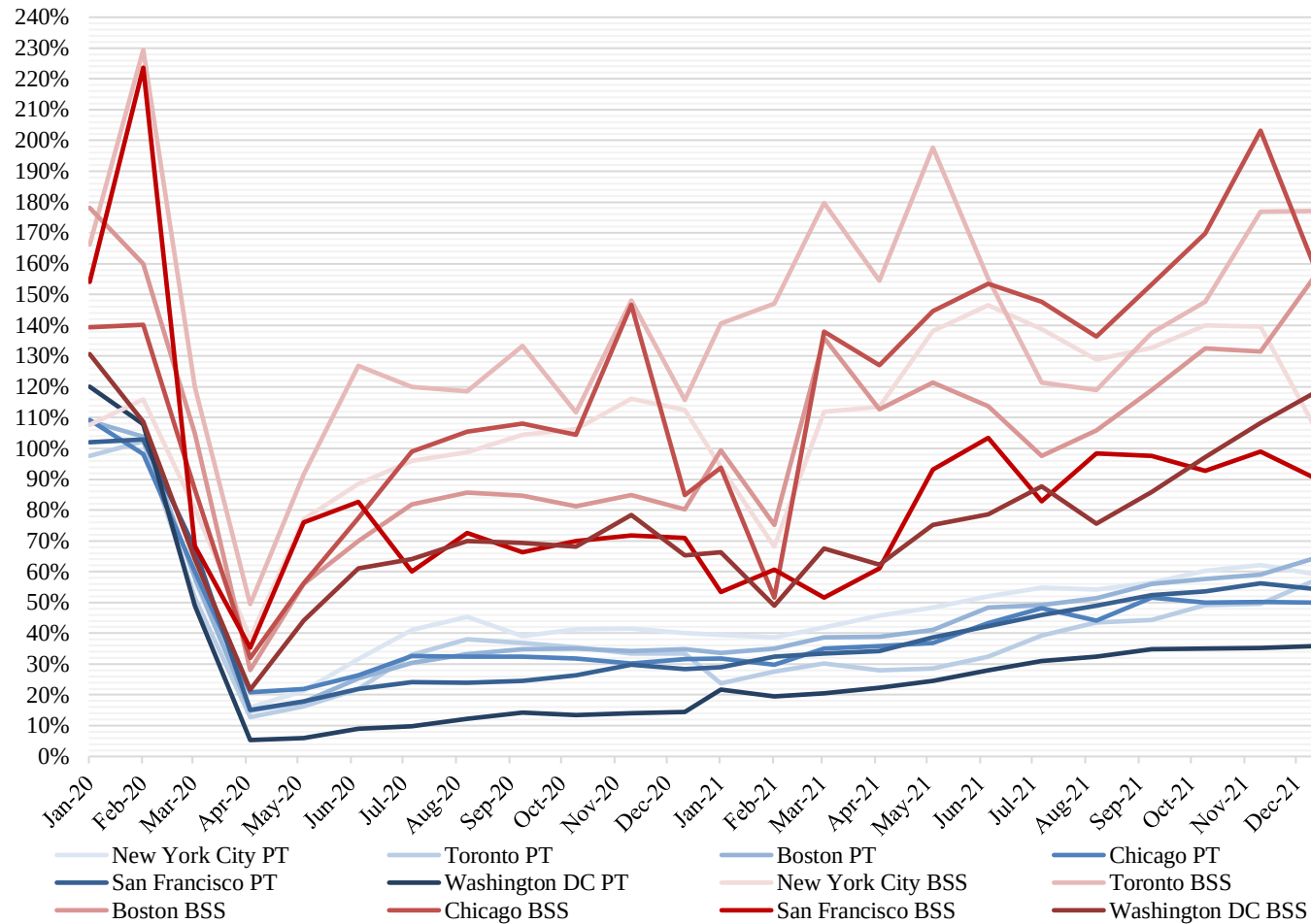


Figure A.1 – Difference on the monthly ridership for bike sharing (in red) and PT (in blue) systems throughout 2020 and 2021 comparatively to 2019 in six North American cities. Note: PT ridership data not available in New York City for January and February 2020

A7. ADDITIONAL ANALYSES FROM CHAPTER 5

A7.1. ALTERNATIVE NON-PARAMETRIC PROCEDURES

Table A.1 – Friedman test results for each period

	Before COVID-19	During COVID-19
<i>N</i>	258	193
<i>Chi-Square</i>	477.685	308.710
<i>df</i>	4	4
<i>Sig.</i>	<.001	<.001

Table A.2 – Post-hoc pairwise comparisons of the motivations for using GIRA and associated Wilcoxon Signed Rank tests before COVID-19 (N=258)

Pairwise comparisons	Number of Ranks		Z
<i>Personal Interests & Well-being vs Service Coverage & Quality</i>	Negative Ranks	134	-2.341 ^b
	Positive Ranks	110	
	Ties	14	
<i>Utility & Competitiveness vs Service Coverage & Quality</i>	Negative Ranks	160	-5.945 ^{*b}
	Positive Ranks	81	
	Ties	1	
<i>Social Influence vs Service Coverage & Quality</i>	Negative Ranks	248	-13.590 ^{*b}
	Positive Ranks	6	
	Ties	4	
<i>Social Discomfort vs Service Coverage & Quality</i>	Negative Ranks	203	-11.255 ^{*b}
	Positive Ranks	42	
	Ties	13	
<i>Utility & Competitiveness vs Personal Interests & Well-being</i>	Negative Ranks	130	-3.592 ^{*b}
	Positive Ranks	89	
	Ties	39	
<i>Social Influence vs Personal Interests & Well-being</i>	Negative Ranks	239	-13.421 ^{*b}
	Positive Ranks	6	
	Ties	13	
<i>Social Discomfort vs Personal Interests & Well-being</i>	Negative Ranks	200	-11.175 ^{*b}
	Positive Ranks	39	
	Ties	19	
<i>Social Influence vs Utility & Competitiveness</i>	Negative Ranks	218	-12.506 ^{*b}
	Positive Ranks	25	
	Ties	15	
<i>Social Discomfort vs Utility & Competitiveness</i>	Negative Ranks	184	-8.577 ^{*b}
	Positive Ranks	58	
	Ties	16	
<i>Social Discomfort vs Social Influence</i>	Negative Ranks	61	-8.093 ^{*c}

	Positive Ranks	167
	Ties	30

*Significant at the 0.05 level (Bonferroni correction for multiple comparisons)

^bBased on positive ranks

^cBased on negative ranks

Table A.3 – Post-hoc pairwise comparisons of the motivations for using *GIRA* and associated Wilcoxon Signed Rank tests during COVID-19 (N=193)

Pairwise comparisons	Number of Ranks		Z
<i>Personal Interests & Well-being</i> <i>Service Coverage & Quality</i>	Negative Ranks	97	-2.363 ^b
	Positive Ranks	80	
	Ties	16	
<i>Utility & Competitiveness vs Service</i> <i>Coverage & Quality</i>	Negative Ranks	116	-5.672 ^{*b}
	Positive Ranks	58	
	Ties	19	
<i>Social Influence vs Service Coverage</i> <i>& Quality</i>	Negative Ranks	186	-11.821 ^{*b}
	Positive Ranks	4	
	Ties	3	
<i>Social Discomfort vs Service</i> <i>Coverage & Quality</i>	Negative Ranks	89	-2.806 ^{*b}
	Positive Ranks	83	
	Ties	21	
<i>Utility & Competitiveness vs Personal</i> <i>Interests & Well-being</i>	Negative Ranks	93	-3.370 ^{*b}
	Positive Ranks	64	
	Ties	36	
<i>Social Influence vs Personal</i> <i>Interests & Well-being</i>	Negative Ranks	181	-11.675 ^{*b}
	Positive Ranks	3	
	Ties	9	
<i>Social Discomfort vs Personal</i> <i>Interests & Well-being</i>	Negative Ranks	90	-1.334 ^b
	Positive Ranks	75	
	Ties	28	
<i>Social Influence vs Utility &</i> <i>Competitiveness</i>	Negative Ranks	168	-11.072 ^{*b}
	Positive Ranks	13	
	Ties	12	
<i>Social Discomfort vs Utility &</i> <i>Competitiveness</i>	Negative Ranks	71	-1.229 ^c
	Positive Ranks	94	
	Ties	28	
<i>Social Discomfort vs Social Influence</i>	Negative Ranks	22	-10.614 ^{*c}
	Positive Ranks	160	
	Ties	11	

*Significant at the 0.05 level (Bonferroni correction for multiple comparisons)

^bBased on positive ranks

^cBased on negative ranks

Table A.4 – Comparison of the motivations for using *GIRA* between the New Users (N=35) and Users Before and During COVID-19 (N=158), as well as the results of the Mann-Whitney U tests and associated significance

Motivations	User type	Mean Rank	Mann-Whitney U test		Differences significant at $p < .05$ (test)
			U	Z	
<i>Service Coverage & Quality</i>	New users	99.586	2674.5	-0.305	No
	Users before and during COVID-19	96.427			
<i>Personal Interests & Well-being</i>	New users	111.329	2263.5	-1.695	No
	Users before and during COVID-19	93.826			
<i>Utility & Competitiveness</i>	New users	98.914	2698.0	-0.226	No
	Users before and during COVID-19	96.576			
<i>Social Influence</i>	New users	114.543	2151.0	-2.081	Yes
	Users before and during COVID-19	93.114			
<i>Social Discomfort</i>	New users	101.086	2622.0	-0.493	No
	Users before and during COVID-19	96.095			

A7.2. CORRECTIONS FOR THE VIOLATION OF SPHERICITY ON REPEATED MEASURES ANOVA

Table A.5 – Repeated measures ANOVA (tests of within-subjects effects) considering the corrections for the violation of sphericity in each period

Sample	Corrections	ϵ	df	F	Sig.	ω^2
<i>Before COVID-19</i>	Greenhouse-Geisser	0.92	3.68	251.95	<.001	0.49
	Huynh-Feldt	0.93	3.74	251.95	<.001	0.49
	Lower-bound	0.25	1.00	251.95	<.001	0.49
<i>During COVID-19</i>	Greenhouse-Geisser	0.86	3.45	175.35	<.001	0.48
	Huynh-Feldt	0.88	3.52	175.35	<.001	0.48
	Lower-bound	0.25	1.00	175.35	<.001	0.48