The Journal of Transport and Land Use jtlu.org
Vol. 17 No. 1 [2024] pp. 401–422

# Exploring the prospects and challenges of sustainable urban mobility: Potential and limits of cycling in Venice

**Cristina Bircu**
Università IUAV di Venezia
cbircu@iuav.it

**Federico Cavallaro**
Università IUAV di Venezia
federico.cavallaro@iuav.it

**Gianfranco Pozzer**
Università IUAV di Venezia
gianfranco.pozzer@iuav.it

**Silvio Nocera** (corresponding author)
Università IUAV di Venezia
nocera@iuav.it

**Abstract:** The Covid-19 pandemic has affected the travel behavior of commuters, with soft modes emerging as reliable options for short-distance trips. This research focuses on evaluating the bike-friendliness of Venice, Italy, a unique city for its morphological and mobility characteristics. When considering daily commuting between the mainland and the historic city center in the lagoon, the bicycle is not an adopted solution. Yet, the recent construction of a bicycle and pedestrian path that runs alongside the main bridge between the mainland and historical city could alleviate the pressure on public transport and the use of cars, especially in peak hours. This contribution evaluates the potential for using bicycles to reach the historic center of Venice from the mainland, and the appropriateness of the infrastructural equipment. The quantitative analysis examines the current supply and demand in absolute values and in terms of modal share. Projecting the number of actual users under different scenarios until 2030, in accordance with the Venice Sustainable Urban Mobility Plan and other relevant plans, the inadequate provision of parking areas for bikes emerges as an unsolved issue. A revision of the mobility layout is thus required if bicycles are expected to be a competitive alternative solution.

**Keywords:** Bike mobility, active transport, accessibility, commuting, Venice

**Article history:**
Received: October 29, 2023
Received in revised form: January 25, 2024
Accepted: April 14, 2024
Available online: May 21, 2024

## 1 Introduction

Since the 1960s, our culture has been predominantly shaped by the concept of car mobility. Infrastructural development has mirrored this trend, designing roads to accommodate car circulation and parking needs. In urban areas, this poses challenges due to limited space and functional conflicts. The resulting intensive circulation of people and goods has fostered the prevalent use of motorized transport for daily journeys, leveraging its higher flexibility (Ribeiro et al., 2022). In suburban and rural areas, the dispersed nature of settlements makes the car the primary choice for daily movements (Poorthius & Zook, 2023). Consequently, cities grapple with high levels of motorized traffic, leading to


https://doi.org/10.5198/jtlu.2024.2448
ISSN: 1938-7849 | 

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

adverse effects on local communities such as air and noise pollution, traffic congestion, and accidents (Nocera et al., 2017; van Essen et al., 2020).

Active mobility, particularly for short-distance trips, emerges as a viable alternative to cars (Bardal et al., 2020). Despite well-known health and economic benefits, the adoption of active travel over car travel remains low in many cities (Orvin et al., 2021). Establishing adequate cycling infrastructure is crucial for overcoming barriers to choosing this option (Wilson & Mitra, 2020). The promotion of cycling as a sustainable transport mode gained momentum even before the Covid-19 pandemic, with several administrations implementing policies and measures to encourage urban cycling (Poliziani et al., 2023; Teixeira et al., 2023). The pandemic further accelerated this trend, with increased bicycle sales and the emergence of temporary bike infrastructure in cities (Rerat et al., 2022), leading to a temporary reduction in transport externalities, including air and noise emissions (Cavallaro & Nocera, 2023).

The Sustainable Urban Mobility Plan (SUMP), introduced at the EU level as a common format of a mobility plan, focuses on improving the efficiency of the transport system and reducing its impact on the environment, social life, and the psycho-physical well-being of daily commuters. Each SUMP is specific to a given territorial area and aims at making it more sustainable in terms of mobility patterns. Yet, the guidelines of the SUMPs advocate for active mobility to cover short-distance trips, ideally reducing the modal share of motorized traffic and associated negative externalities (Rupprecht et al., 2019). Active mobility encompasses pedestrian and bike movements, covering trips shorter than 2 km and 15 km, respectively (Vale & Pereira, 2016). While SUMPs outline changes in modal share, their strategic focus do not allow addressing infrastructural design and equipment.

Culturally, the use of bicycle for urban trips is typical of certain countries, primarily in Northern Europe (Schneider et al., 2023). Academic contributions on the impacts of bicycles on urban mobility are more extensive in these regions, contributing to the widespread acceptance of cycling for daily movements. In the south-European countries, academic contributions are more limited, with a higher interest emerging only in the latest years. This paper contributes to increase the knowledge about bicycle as a reliable travel option in these regions, by focusing on the Italian city of Venice. Venice is chosen as a case that is worth to be investigated due to its unique territorial and morphological layout, which prohibits the use of bicycles in its historic center. In this pedestrian-only environment, the selection of the options that allow an easy access to the city becomes pivotal. The city has recently developed a cycling infrastructure that connects the mainland to the historic center in the lagoon. This infrastructure, which has been primarily conceived for tourists, as last-mile connection of the international cycleway "Munich-Venice" (Muenchen-Venezia, 2023) and other regional cycleways, may become useful also for commuters and systematic mobility. Yet, the SUMP of Venice, which covers the whole metropolitan area, does not consider this connection strategic for this type of connections.

The paper aims to evaluate the potential modal choice implications resulting from the introduction of the bike lane between the mainland and the historic city center of Venice. It quantifies its potential use and implications for modal split by analyzing current infrastructural equipment and evaluating its adequacy for expected or potential users. This evaluation helps gauge the potential of this connection, especially for systematic mobility and commuters. The paper is structured as follows: after this introductory section, Section 2 provides a brief literature review on the role of bikes in systematic mobility, including their advantages and limits. Section 3 presents the method adopted to calculate existing and future levels of bike flows for commuting reasons. The method is then applied to verify the introduction of a bike connection between the mainland and the historic center of Venice (Section 4). Section 5 discusses the results and compares them with relevant national and international experiences. A conclusive section that brings key messages to a more general level ends the contribution.

## 2 Literature review

The following literature review aims at understanding a) which factors influence the choice of cycling as a reliable transport option and b) how cities can promote it. Active travel modes as a reliable solution to cover short-distance systematic trips have been the object of studies in north-European countries since the beginning of the last decade (Johansson et al., 2012; Stigell & Schantz, 2015). Since then, an increased interest in this topic has been registered, mostly considering the beneficial health effects (Ek et al., 2021). With the diffusion of Covid-19, literature on such issue has proliferated, also insisting on the benefits against the diffusion of the virus (Tao et al., 2023).

The design of the network in the city is a first aspect worthy to be investigated, especially in those contexts characterized by a high use of cars and the presence of limited roads to access the city (such as the case study described in Section 4). The critical factors generated by a car-based mobility, such as congestion, emissions, sedentary lifestyles, and social and territorial fragmentation threaten the livability of urban areas (Lanzerdorf et al., 2022). Therefore, it is essential to identify effective strategies for reducing car use, promoting active and sustainable mobility, rethinking urban space, and improving accessibility to services and functions. Several studies agree that cyclists are sensitive to distance, turn frequency, gradient, intersection control, traffic volumes, travel times, parking, and speed limits (Agarwal et al., 2020; Lou et al., 2020; Ribeiro et al., 2022). The needs of cyclists have rarely been considered in the initial definition of urban mobility, and only ex-post solutions have been attempted to introduce cycling as an option to move in the city. According to Saplıoğlu and Aydın (2018) they require suitable gradient, separate lanes, continuity of the infrastructure and routes. Encouraging individuals to shift to more sustainable transport modes is crucial particularly in dense urban areas characterized by limited space. This should be achieved by adopting a multi-modal approach with particular emphasis on the infrastructural design for bicycle. Physical connectivity between different territorial areas is the most important aspect of uninterrupted door-to-door travel (Wysling & Purves, 2022). To overcome the systemic barriers, it is essential to have a well-planned and targeted cycling network and adequate parking areas (Bardal et al., 2020). Without a direct connectivity, users may resort to alternative, often private, transport solutions. In suburban areas, whose layout and density are different compared to urban areas, bike expressways can be designed to provide a direct network of routes, reducing travel times and costs (Agarwal et al., 2020).

Beside the network design, other factors influence the choice of bike as transport option. In particular, social and economic factors and travel characteristics, including the natural environment, play an important role (Yanar, 2023). As each city has its own morphology and urban characteristics, it is important to understand the common factors that lead to more sustainable transport choices. Acharjee and Sarkar (2021) seek to investigate the effects of the characteristics of the built environment on modal choice, looking at three urban areas based on different land uses through the lens of the entropy index. This index shows that in areas with a higher functional mix, people make shorter trips, thus making cycling a reliable option. Conversely, low-density areas are characterized by longer trips, which tend to reduce cycling. It is important to promote cycling using various strategies. Through targeted and limited infrastructural interventions, cities can significantly increase cycle connectivity, not only towards the center, but also with adjacent neighborhoods, where short car trips could be replaced by cycling.

Hidalgo-Gonzales et al. (2022) identify behavioral patterns and the main barriers to commuting. According to their analysis of university commuters carried out in Léon (France), the most important barriers to the use of bicycles are unsafety and thefts at the university. One of the most serious causes of concern is traffic risk (Bosen et al., 2023). Accident involving active travelers are frequent and have severe impacts on vulnerable users (Ma et al., 2021). In several urban contexts, the highest number of traffic-related deaths involves cyclists or pedestrians, thus confirming the vulnerability of such categories. The introduction of protected lanes allows a dedicated space for cyclists, which in turn promote a significant correlation between a low-stress network and the share of cycle commuters (Cabral et al., 2019; Wang et al., 2020). Finally, the exposure to traffic pollution is another negative factor, that influences the modal choice (Luo et al., 2020). As primary pollutants are more concentrated near the sources of emission, the segregation of cycle lanes and the distance from vehicular traffic may contribute to overcome this criticality.

Despite these negative aspects, several benefits should be considered, as well. Cycle paths have been found to improve the quality of urban life for residents and their sense of security (Lanzendorf et al., 2022). Besides the health aspects mentioned at the beginning of this section, cycling has a great potential to improve mental well-being. Bike users for daily commuting have less psychological distress and greater life satisfaction than those who do not use it. Ma et al. (2021) highlights the potential mental benefits of cycling and the importance of including them into active mobility policies, not only to encourage the adoption of cycling but also to encourage more frequent use for daily commuting. The bicycle is seen as an ecological and low-cost alternative to meet mobility needs, helping to democratize the city and expand social relations (Lopes et al., 2021). From an environmental perspective, and only considering its use, the bike option produces a zero level of pollutant emissions (Maggi et al., 2021).

Table 1 shows relevant contributions dealing with the improvement of bike mobility in urban areas. These studies are divided into qualitative or quantitative ones, according to their nature and the adopted methodology. The study is classified as "quantitative" if the analysis is made in numerical terms and it is possible to quantify the incidence of bike mobility over other solutions and their variation after the implementation of a specific measure. Vice versa, if the relationship between land use and the development of bike mobility is not expressed in numerical terms, the study is labelled as qualitative. Most of the studies are concentrated in northern Europe including Denmark and the Netherlands, as well as certain areas of Portugal and Northern America. This is not a coincidence: such areas present an urban design that allows the introduction of extensive cycling network and in some cases, they are supported by a culture that encourages cycling over car use (Schneider et al., 2023). On the other hand, south European countries have received less attention. This is due to several reasons, including different behavioral choices of commuters, as well as city design and the infrastructural equipment with adequate cycle lanes, which is often complicated by the presence of old cities and narrow streets. Maas et al. (2021) suggest that, due to the region's thriving tourism industry, cycling in this area is mostly a leisure activity rather than a means of transport. The Italian city of Venice is paradigmatic in this sense, due to its Mediterranean location and unique conformation. To the best of our knowledge, no contribution has yet evaluated the implications on systematic commuting deriving from a properly developed cycle network in this context.

**Table 1.** Literature review on bicycle as a transport solution for systematic mobility

| Source | Geographic area | Topic | Key message | Approach |
|---|---|---|---|---|
| Acharjee and Sarkar (2021) | India | Potential of increase bicycle in city | More policies to encourage people to use bike as a mode of transport | Qualitative |
| Agarwal et al. (2020) | India | Bike-sharing | Bicycle superhighway increases the use of bicycling and reduces emissions significantly | Quantitative |
| Bardal et al. (2020) | Norwegian cities | Health benefits of active transport | Identified barriers and success factors | Qualitative |
| Bosen et al. (2023) | Germany | Cycling perception, urban pollution, mitigated risk | Taking more road space could mitigate cycling risk | Qualitative |
| Cabral et al. (2019) | Canada | Connected and safe bicycle network | Four-fold increase in connected origin-destination pairs | Qualitative |
| Ek et al. (2021) | Sweden | Accessibility for cycling | Availability of safe routes is important for cycling | Qualitative |
| Hidalgo-Gonzales et al. (2022) | France | Commuting for students | Is necessary to foster practical learning to improve motility and consolidate cycling | Quantitative |
| Johansson et al. (2012) | Sweden | Commuting for students | Active commuting decreases with age, while public transport increases | Qualitative |
| Lanzerdorf et al. (2022) | Germany | Cycle infrastructure as a key role in urban spaces | Varied perceptions based on mode use and sociodemographic characteristics | Qualitative |
| Lopes et al. (2021) | Portugal | Active commuting for students | High accessibility to schools and urban centralities common in high cycling potential areas | Quantitative |
| Lou et al. (2020) | California | Cycling perception, urban pollution, mitigated risk | Considering exposure to traffic-related air pollution can change the results of bicycle route planning | Quantitative |
| Ma et al. (2020) | Netherlands | Cycling factors | Factors affecting people's modal shift in commuting revealed | Quantitative |
| Ma et al. (2021) | Australia | Health benefits of active transport | Bicycling is negatively associated with psychological distress and positively associated with life satisfaction | Quantitative |
| Maggi et al. (2021) | Italy | Commuters' factors | Combination of price-based policies and preference-based policies produces the best outcomes | Quantitative |
| Maas et al. (2021) | Mediterranean cities | Bicycle sharing systems | Cycling in coastal areas is dominated by leisure use | Quantitative |
| Orvin et al. (2021) | New Zealand; Canada | Spatial and Temporal factors in cycling network | Significant differences were found in variables related to land use, weather, built environment, traffic, neighborhood, and bicycle facilities | Quantitative |
| Poorthius and Zook (2023) | Netherlands | Implementation of 15-minute city | The challenges and importance of considering car reliance and accessibility in non-urban neighborhoods | Qualitative |
| Ribeiro et al. (2022) | Portugal | Benefits of active mode of transport | Health-friendly routes reduce exposure to pollution and noise | Qualitative |

| | | | | |
|---|---|---|---|---|
| Saplıoğlu and Aydın (2018) | Australia | Accessibility for cycling | Bus lanes and roadside car parks are important factors in integrating cycling with a PT system | Qualitative |
| Schneider et al. (2023) | Netherlands | Cycling distances and factors | High urban density should be favoured to increase the probability of cycling | Quantitative |
| Stigell and Schantz (2015) | Sweden | Benefits of active mode of transport | Majority of commuting trips met health recommendations | Quantitative |
| Tao et al. (2023) | UK | Commuting and wellbeing | Long distances commuting increases the preference to work from home | Quantitative |
| Teixeira et al. (2023) | Portugal | Bike sharing to reduce car trips | Users replacing car trips are more sensitive to travel cost reductions | Quantitative |
| van Kampen et al. (2021) | Copenhagen | Bicycle facilities | Building density increases cycling towards other stations | Qualitative |
| Wang et al. (2020) | Ohio | Bicycle network and commuting | Low-stress road segments are positively associated with bicycle commuters | Quantitative |
| Wilson and Mitra (2020) | Canada | Safety for cycling infrastructure | Four strategies used to implement cycling infrastructure | Qualitative |
| Wysling and Purves (2022) | France | Safety for cycling infrastructure | Bikeability map: where to improve bike network | Quantitative |
| Yanar (2023) | California | Commuting factors | Modal choices are affected by many parameters | Quantitative |
| Zhao et al. (2018) | China | Bicycle infrastructure as a challenge | Identifying strengths and weaknesses of bicycle infrastructure planning | Qualitative |

## 3 Method

The method presented in this section quantifies the expected future demand of systematic mobility by bike along relevant cycle lanes, in accordance with the numerical indications provided by the main mobility plans developed for a specific location. Subsequently, it verifies whether the current infrastructural equipment for bicycle is able to satisfy the demand previously calculated. In case of negative answer, the quantification of the required space for the service is provided, to ensure its coherency with the forecasts indicated in the mobility plans.

As visible from Figure 1, the first phase of the method provides a comprehensive understanding of the territorial context and how it is characterized in terms of infrastructural supply (*S*) and demand (*D*). The analysis aims at defining the existing infrastructural connections and transport alternatives ($S_0$), as well as at quantifying the number of daily movements and modal split ($D_0$), in order to understand the incidence of bike mobility. The focus of the analysis is on systematic mobility for school and working reasons, which includes those trips that are most suitable for considering a shift towards bicycle. Furthermore, only those movements below a certain distance are considered. In the case of bike mobility, we selected this threshold in 10 km, a distance that can be covered by bike in about 30 minutes.

In parallel (phase 2), the main indications provided by urban plans concerning the city's future travel demand ($D_k$, with $k=1,..,n$ according to the different forecasts) are assessed, both in terms of variation of movements and modal share. Normally, the former are expressed as variation in the percentages of the daily movements, whereas the latter are indicated as a target percentage to be reached. Absolute quantitative values are rarely available, thus hindering the possibility of understanding the real implications on circulation along main pieces of infrastructure (here also including the cycle lanes).

The current modal share and the percentage of future forecasts that each plan takes into account are combined in the third and final step (phase 3). This is carried out by proposing $k$ alternative scenarios (as defined above), which are compared with $D_0$, to obtain a predictable number of bicycle trips. The focus is on the bike component, to assess the suitability of its infrastructure to the expected demand. In each scenario, a percentage in the use of bicycle is obtained according to the indications obtained in the urban mobility plan. This is then transformed into number of trips, with a contextual redistribution of the trips by other transport modes. With such an information, it is possible not only to highlight the growth trends and projections in relation to the expected growth in the use of bicycle, but also the total amount of movements with other transport solutions. Yet, our main target is to understand whether the existing cycle infrastructure can support the increased bike demand or, alternatively, targeted interventions are needed (see last part of Phase 3, in Figure 1). These outcomes may help policymakers to understand which investments and modifications to existing mobility layout must be provided not only as limited to cycling, but also including road traffic and related spaces.

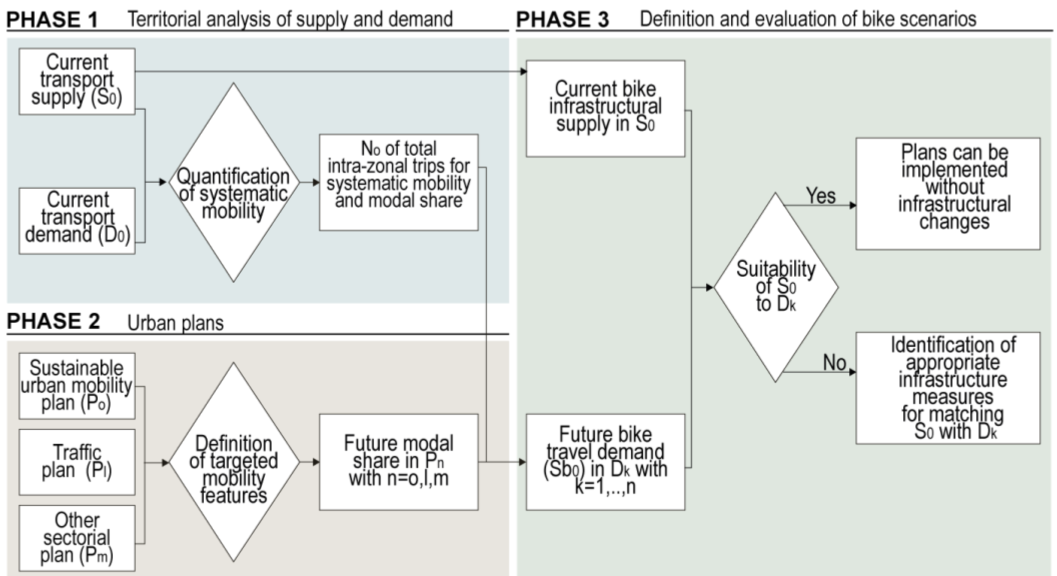


**Figure 1.** Method for assessing future incidence of bike mobility on systematic commuting and the appropriateness of existing infrastructural equipment

## 4 Case study: Historic center of Venice and the connections with the mainland

### 4.1 Infrastructural supply and transport services in Venice

Venice is one of the few cities that in the collective imagination cannot rely on bicycle as an option to reduce its dependence on motorized traffic. At a first glance, the ban of motorized vehicles and bicycles in its historic center and its water connections with several minor islands make it ideal for assessing the potentialities of maritime or pedestrian sustainable mobility, rather than bicycle. Yet, the municipality is composed also by a mainland part, which includes the agglomerations of Mestre and Marghera. They are part of the municipality of Venice and is home to most of the citizens that daily commute to the historic city center. This part is connected to the historic center of Venice, located in the Venice lagoon, by a multimodal road and rail infrastructure, i.e. the Liberty bridge (Figure 2). Since its opening in 1846, the Liberty bridge has been the main connection to the historic center of Venice: first by railway, then including also a road. In

2014 a tramline was also built, thus increasing the alternatives to reach the historic center of Venice. In addition, a segregated cycle and pedestrian lane opened partially to the public in 2018, with the completion of the final section in 2022. As a result of this evolution, the bridge allows several alternatives, including public transport (PT) by bus, tram and rail, private motorized vehicle, and bicycle.

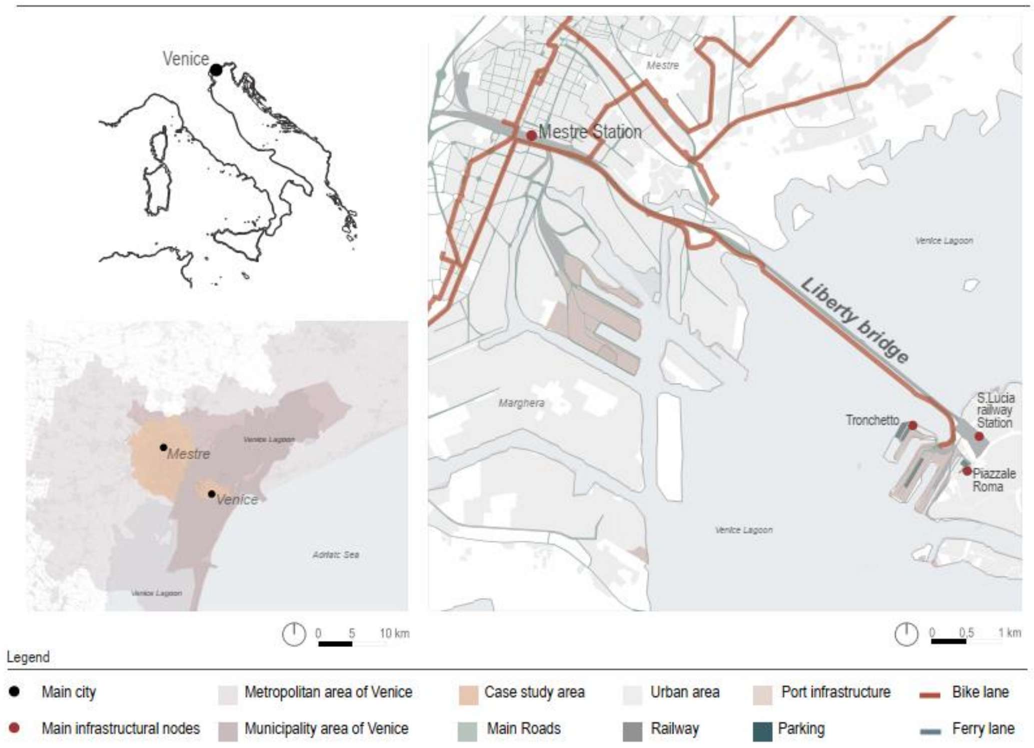


**Figure 2.** Venice and its infrastructural layout between the mainland and the lagoon

Railway connections are guaranteed by the 4 tracks that connect Venice Mestre (13 platforms) to Venice Santa Lucia train station (24 platforms). The train connections are mainly operated by Trenitalia. Other operators (Italo, Sbb and Obb) are not considered here, as they operate only high-speed and long-distance trains that are not coherent with the local scale considered in our analysis.

As regards road transport, a 4-lane road (with 2 lanes per direction) connects Venice Mestre to Venice historic center; 2 of them are shared by trams and other road vehicles, including urban, suburban, and tourist buses, as well as heavy goods vehicles. Two main hubs are conceived for the arrival of road vehicles in the historic center of Venice: Piazzale Roma (mostly for taxis, trams, urban and suburban buses) and Venice Tronchetto, the port terminal of Venice (mainly for private cars and private buses). Piazzale Roma is more central (connected to the Santa Lucia train station by a pedestrian bridge), but also more expensive: a daily parking costs up to 45€ for cars. Tronchetto is more peripheral, less expensive (25€ for a daily pass) and connected to Piazzale Roma with a people mover. The tram goes from Favaro to Piazzale Roma, passing through the center of Mestre. The connections by buses and lagoon water boats are operated by AVM/Actv. Daily, almost 100 trams and 500 buses cross the bridge from Mestre to the historic center. Table 2 shows the number of daily connections from Venice to the main origins/destinations crossing the Liberty bridge during the months September-June.

**Table 2.** Main connections between mainland and the historic center of Venice

| PT headed to Venice S. Lucia - Piazzale Roma | | | |
|---|---|---|---|
| Transport mode | Operator | Main origins | Rides/day |
| Ferry | Alilaguna | Marco Polo Airport | 20 |
| | AVM S. p. A. | Fusina Terminal | 26 |
| Road PT | AVM S. p. A. | Mestre Train Station | 90 |
| | | Mestre Center | 112 |
| | | San Giuliano | 59 |
| | ATVO S. p. A. | Marco Polo Airport | 39 |
| | | San Donà di Piave | 26 |
| | | Jesolo Lido | 28 |
| | | Latisana | 15 |
| | | Caorle | 16 |
| | | Bibione | 11 |
| | | Trepalade | 15 |
| | | Fossalta di Piave | 8 |
| | Arriva Veneto | Chioggia/Sottomarina | 53 |
| Train | Trenitalia S.p.A. | Padova (Verona) | 32 |
| | | Padova (Bologna) | 29 |
| | | Vicenza | 12 |
| | | Trieste (Udine -Treviso) | 15 |
| | | Trieste (Portogruaro) | 30 |
| | Sistemi Territoriali | Rovigo | 14 |
| | | Adria | 15 |
| Tram | AVM S. p. A. | Favaro | 96 |
| | | Total | 761 |

Finally, the 6.8 km cycle lane from Mestre to Venice covers most of the distance between the Mestre and Santa Lucia stations (10 km) segregated from the main road, thus guaranteeing a protected and safe connection between the two parts of Venice. Considering the distance between origin and destination, a traveler can arrive in the historic center conveniently and safely while avoiding vehicular traffic. Hence, it could represent a valid alternative for proximity movements, provided that the parking places are sufficient to cover the potential travel demand. Currently, this infrastructural equipment is limited. In Venice historic center, there is only a bicycle park in Piazzale Roma called “Bicipark”, located in front of the entrance to the municipal covered parking area (daily and monthly cost are 10€ and 25€, respectively).

### 4.2 Current travel demand to reach the historic center of Venice

The infrastructural layout and the transport alternatives described above are expected to guarantee the proper connection between the lagoon and the mainland. Yet, the balance that has been achieved in terms of supply and demand is far from being satisfactory. In terms of travel demand, the Santa Lucia railway station is the departing and/or arrival station for more than 29,000 passengers per day (SUMP, 2020b), with a peak during rush hours of 3,650 passengers entering Venice and 650 departing from the station. According to the data gathered for the SUMP of Venice (2020), the Liberty bridge supports high-road traffic volumes. Every day the Liberty bridge is crossed by about 30,150 private vehicles, 11,150 of which are headed towards Tronchetto, and 19,000 continue to Piazzale Roma, which is the main arrival node of the historic center of Venice. As for PT, 23,000 passengers depart from Piazzale Roma, while 21,000 passengers arrive daily (PUM-AV, 2009). Overall, in the node of Piazzale Roma – Santa Lucia, a daily total of 100,000 passengers arrives and is direct towards the heart of the historic center (SUMP, 2020a). Considering that the population living in the historic city center is below 50,000 inhabitants, this quantity represents more than the double of the city population, concentrated in a single node.

For such reasons, relying on bicycle as an alternative to reach Venice may be a partial solution to achieve a more balanced share and reduce the pressure on the existing forms of transport. The catchment area of bike demand coincides with the whole municipal area of Venice. Indeed, recalling the threshold of 15 km as maximum distance covered by a standard biker, the distance between Piazzale Roma and the fringes of Marghera and Mestre is always below such value. Yet, bicycle is currently not an option: despite the opening of the bike lane, some negligible daily movements are registered, but they are mostly due to tourists that run the international or regional pathways or to local inhabitants that travel by bike for leisure purposes. As a result, the modal split to reach the historic center of Venice is as follows (SUMP, 2020b): 33% cars and motorcycles, 29% trains, 18% urban buses, 12% tourist buses, 5% trams, 3% people mover. For the purposes of this paper, this last option has been subtracted from the total, since people using it are those who reach Venice and park their car in Tronchetto (see 4.1). The current modal share ($D_0$) to reach Venice is presented in Table 3. Of overall trips headed to Venice, 35% continue their journey from the station to the central areas of the city by water PT, while the remaining 65% choose to walk. In both cases, people need to change means of transport to move within the city. Yet, this part of the trip is not covered by our analysis.

**Table 3.** Modal share to reach the historic center of Venice. Source: own elaboration on SUMP (2020a)

| Daily modal share ($D_0$) to reach Venice S. Lucia - Piazzale Roma | | |
|---|---|---|
| Means of transport | Daily users | % |
| Private motorized vehicles | 34,600 | 41 |
| Bus | 17,400 | 20 |
| Tram | 5,300 | 6 |
| Train | 28,000 | 33 |
| Bicycle | 0 | 0 |
| Total | 85,300 | 100 |

This overall travel demand along the Liberty bridge is then split between systematic and non-systematic mobility. The aim is to understand the potentialities of bike system as an alternative to reach the city and reduce the pressure on road and rail transport. As the information is not available on such a disaggregate level, we refer to the whole municipality of Venice to detect the number and percentage of inter-municipal movements. The percentage found is used as a proxy to obtain the number of movements that are performed daily at city level. In its latest available report, the Italian National Institute of Statistics (Istat, 2011) has calculated daily trips involving the municipality of

Venice as 490,190. 183,606 of them are trips generated outside the municipality and headed to Venice; 193,877 depart from the municipality of Venice and reach other destinations. Finally, 112,707 are inter-municipal trips, which represent 23% of the total city movements. By recalling the total number of trips headed to the historic center of Venice and applying the percentage calculated above, we can estimate that roughly 22,300 daily trips along the Liberty bridge are generated within the municipality of Venice. Some socio-economic data may help interpret the quantities and understand reasons for such movements towards Venice. As previously mentioned, most of the people live in the mainland (about 4/5 of total population). Yet, the historic center of Venice represents a main destination for working reasons: as one of the most touristic cities in Italy (595,000 arrivals in 2019), the hospitality sector offers numerous jobs for the local population (Città di Venezia, 2022). In addition, there are roughly 1,000 economic activities in the historic center of Venice, including bars, restaurants, and public facilities, employing a total of approximately 30,000 people. Moreover, 12,000 people are employed in agencies, rental and business services. As a sum, the number of employees in the private sector for the historic center of Venice is about 112,000 (Vendettuoli, 2019). Furthermore, education is another important driver for local movements. The city center of Venice hosts the two main state universities: Università Iuav di Venezia and Ca' Foscari (ca. 25,000 students in 2021/2022). Almost 1,500 of them arrive from the municipality of Venice (Istat, 2019), thus representing another relevant component of systematic mobility. To this component, the number of academic and administrative staff needs to be added. The population living permanently in the Venice historic center is less than 50,000 out of 176,832 inhabitants in the entire Municipality of Venice (2023). Hence, it is reasonable to consider that a non-negligible part of the workforce comes from the mainland.

### 4.3 Future transport system according to mobility plans: Bicycle objectives

As one of the most delicate ecosystems in the world, Venice is the object of interests of several plans, belonging to the different sectors. Some of them deal specifically with mobility. Within this section, we highlight their objectives in terms of more sustainable mobility, contributing to a shift from private transport to cycling (Table 4). The first plan is the Biciplan, which sets specific goals for bicycle mobility. Then, we consider the SUMP (2020a) of the metropolitan area of Venice. Finally, we analyze the plan called 'Venice like Boston", which is a project carried out by the university IUAV (Iuav, 2022). The contents of these plans are the basis for defining scenarios $D_1$, $D_2$ and $D_3$.

*a) Biciplan* (2020). It is a sectoral transport plan specific for bike lanes. It aims at completing the cycle network of the metropolitan city of Venice, giving priority to the connections between stations, terminals, universities, high schools, and other provincial attraction poles. This target is in line with the evolution of bike mobility in the city, which passed from 3.7% of daily movements in 1991 to 5.4% in 2001, with a further increase to 6% in 2011. In 2009 the city of Mestre fixed the objective to complete a 70-km cycle network of main routes (37 km already existing), to be connected to 22 km of existing secondary routes and 7 km inside city parks should guarantee about 100 km of cycle lanes (PUM-AV, 2009). Among them, the cycle path connecting Mestre and Venice (which is a section of the regional line that connects Venice to Treviso and is the object of our analysis) was built between 2014 and 2022. This infrastructure is conceived both for daily commuting, as well as for recreational and tourist activities. The goal of such an infrastructural development is to increase bike users by 30% as compared to 2011 levels. The Biciplan foresees the development of 168 km more of cycle network by 2030, improving cycle connections in the Metropolitan area to a total of 435 km. An analysis of the potential catchment area indicates in 445,000 inhabitants those living within 500 m from the planned cycle network. Finally, to support cycling mobility, the plan is not only to invest on the linear infrastructure, but also on the punctual one: the Biciplan indicates an increase in the number of bike stations and a stretch of cycle path between the Liberty bridge, passing through Piazzale Roma and to San Basilio as a final destination, to serve the city's main university headquarter and facilitate the subsequent connection to the navigable network. In addition, 75 new cycle stations were planned at strategic points. Five of them are in Venice near Piazzale Roma, 3 in Mestre and 2 in Porto Marghera.

*b) SUMP of Venice (2020a).* Acknowledging the primary role of private motorized mobility on overall movements, the SUMP of the Metropolitan City of Venice sets some ambitious targets until 2030. In the reference scenario a reduction in total road vehicle trips is expected, with values around -6% compared to the current condition. Among the measures proposed for achieving such a goal, limiting the traffic volumes along the bridge is relevant for its potential implications. Beside this push-measure, an improvement of the performances guaranteed by other alternative systems is planned. The primary aim is to ease the burden on the multimodal node Tronchetto-Piazzale Roma-Santa Lucia railway station. This can be achieved by increasing the number of connections between the mainland, the historical center of Venice, and the other lagoon islands. To this aim, a new multimodal terminal at San Giuliano (Mestre), which will enable commuters to easily switch between regional trains and lagoon navigation services running to the historic center of Venice, should alleviate the congestion caused by passenger rail and road traffic along the Liberty bridge. This measure is flanked by an improvement and extension of water PT services between main stops in the lagoon (also including the Santa Marta area) and the new San Giuliano stop. This will reduce the overall travel time to reach the main poles of attraction located in the heart of the historic center but far from the Piazzale Roma and Santa Lucia intermodal node. Currently, people headed towards such destinations have not alternatives than going to the Piazzale Roma-train station area and then catch the ferry boat. In the future, with these new water links, this would not be necessary. Moreover, according to the models carried out for the SUMP, it has been estimated that up to 50% of the journeys under 750 m can be transferred to bicycles; this percentage decreases to 30% of those between 750 and 1,500 m and further lowers for progressive distance bands. In total, a decrease in total vehicular journeys of about 5,500 vehicles-km could be achieved, equivalent to a drop by -0,5% compared to the current traffic condition. As part of this strategy, the cycle lane between the centers of Venice and Mestre should become an important connection at urban level.

*c) Venice like Boston (2022).* To double the student population by 2030 and revitalize the historic center of Venice, Università IUAV di Venezia has elaborated a project called "Venice like Boston" with the support of the Municipality of Venice. Venice has become a highly sought-after location for university students, with 8% of the total population being enrolled in academic programs. By increasing the number of university students (+30,000 students compared to current levels), the city is expected to have a new positive demographic trend, considering all satellite activities. Boston is cited as a reference for this type of initiative. More in detail, the objective is to build a new urban campus located between Mestre and the historic center, with the area of Santa Marta as its focal points (Figure 3). This area consists of several university campuses belonging to both city universities. Transport-wise, the project entails a tram and bus connection between Venice and Mestre. Yet, the use of bicycles is seen as a valid alternative and fully coherent with the purposes of our research: students are target users of the service and the systematic nature of their movements is unquestionable. Moreover, the main university buildings can be reached directly from the mainland, by using the cycle lane along the bridge and passing through the port area, which is a 20-km/h zone already open to pedestrians. This would mean that beside Piazzale Roma, also Santa Marta can become an alternative destination of the historical center of Venice, if properly equipped with racks and facilities for bikes.

**Table 4.** Synthesis of three alternative scenarios for the infrastructural development of Venice

| Plans dealing with future bike mobility for Venice | | | |
|---|---|---|---|
| | Biciplan (2020) | SUMP (2020a) | Venice like Boston (2022) |
| Target area | Metropolitan city of Venice | Metropolitan city of Venice | Venice historical center |
| Transport mode | Bicycle | PT, cars, park and ride | Connectivity by PT and soft mobility |
| Objective | Increase and connect the existing infrastructure network; improve accessibility to infrastructure hubs; improve infrastructure quality; reduce the number of cyclist fatalities by 50 per cent by 2030. | Reduce of 6% in car use; achieve effectiveness and efficiency of mobility; increase energy and environmental sustainability; increase road safety; socio-economic sustainability. | 30,000 students more in Venice historical center; a new campus between the mainland and the historic city center; infrastructure regeneration between Piazzale Roma and Santa Marta; new electric bus lane from Via Torino (Mestre) to Santa Marta (Venice historic center). |

### 4.4 Potential of cycle lane for daily mobility

To understand the effects deriving from the use of the new bike lane along the Liberty bridge, we propose the development and appraisal of different scenarios based on the socio-economic and mobility projections expressed in the Biciplan, SUMP and Venice like Boston plans (corresponding to scenarios 1, 2 and 3, respectively). The purpose is twofold: first, to calculate in quantitative terms the number of potential users among those that commute daily in different scenarios; and second, to evaluate whether the current infrastructural equipment ($S_0$) and city layout is adequate for such a change in the modal split, or adjustments are required. As shown in Table 3, only the systematic component of mobility is considered: modal share related to tourist buses has been excluded from the analysis, and percentages have been redefined accordingly.

As mentioned above, the reference scenario is 0, with current modal share and number of trips along the bridge as described in Section 4.2. Absolute values have been derived from the revised travel matrix provided by ISTAT, which considers only the systematic component of mobility along the Liberty bridge, as described in Table 3. The total number of daily movements is 19,613. The modal split in $D_0$ is derived from the analyses included in the SUMP of Venice, which lead to the following distribution: 7,955 trips by private car, 4,001 trips by urban busses, 1,219 trips by tram, 6,438 trips by train. Trips made by bicycle on the Liberty Bridge are not considered, reflecting the current situation.

As regard other scenarios, in accordance with the indications included in the three scenarios presented above (Section 4.3), a 3% of total modal share is foreseen for bicycle usage on the Liberty bridge in Biciplan ($D_1$), which rises to 6% in SUMP ($D_2$) scenario (also according to the fact that SUMP aims to reduce cars by such a percentage), and 8% in ($D_3$). These variations affect the modal share of other options, which have been reduced accordingly (Table 5). Percentages have been then reported in absolute values, indicating that the daily number of bicycle trips in Venice Municipality can rise to 1,531 in $D_3$.

**Table 5.** Systematic travel demand along Liberty bridge in alternative scenarios

| Means of transport | Current demand ($D_0$) | | Biciplan ($D_1$) | | SUMP ($D_2$) | | Venice like Boston ($D_3$) | |
|---|---|---|---|---|---|---|---|---|
| | Daily users | % | Daily users | % | Daily users | % | Daily users | % |
| Private motorized vehicles | 7,955 | 41 | 7,563 | 39 | 7,171 | 37 | 7,060 | 36 |
| Bus | 4,001 | 20 | 3,805 | 19 | 3,707 | 19 | 3,622 | 18 |
| Tram | 1,219 | 6 | 1,219 | 6 | 1,121 | 6 | 1,053 | 5 |
| Train | 6,438 | 33 | 6,438 | 33 | 6,438 | 33 | 6,346 | 32 |
| Bicycle | 0 | 0 | 588 | 3 | 1,177 | 6 | 1,531 | 8 |

With such figures, the real issue seems the infrastructural supply ($S_0$) of parking areas for bikes. Differently from private vehicles, which can count on a total of 7,000 parking spaces and is in line with current and future demand, parking facilities and spaces for bicycles are more limited. The three scenarios show the significant differences that exist between the available infrastructure and the potential increase in bicycle use. The realization of such projections and related mobility policies depends primarily on the underlying infrastructure conditions. In 2023, the only service available in the area of Piazzale Roma is the Bicipark, which offers 100 parking spaces for bicycles and is mainly aimed at tourists arriving in Venice historic center by bicycle (AVM s.p.a., 2023). Obviously, this service is not sufficient to cover the travel demand in other scenarios and the current costs do not allow a realistic use.

However, when sizing adequate spaces, it must be considered that not all trips end at Piazzale Roma. Indeed, some of them are headed towards Santa Marta and this percentage varies according to the considered scenario. For instance, the Venice like Boston scenario, which is the most ambitious, is expected to have a higher percentage of movements towards this destination than other scenarios. In this case, we assume that 60% (919) of total bike trips are headed towards Santa Marta and the remaining 40% (613) are headed towards Piazzale Roma. In sizing the parking facilities ($D_{1-3}$), we must also consider that the flow of bikes in Piazzale Roma and Santa Marta is not simultaneous, i.e., all bikes are not parked at the same time. The turnover is hypothesized at 30% of the total arrivals. This reduces the capacity of the service at 70% of total values, which means 429 bicycles in Piazzale Roma and 643 bicycles in Santa Marta as maximum values reached in $D_3$ (see Table 6 and Figure 3). According to the Metropolitan Transport Observatory, each parking place requires a minimum surface of 1.8 $m^2$ (Eltis, 2023). This means that 772 $m^2$ and 1,158 $m^2$ are requested in Piazzale Roma and Santa Marta, respectively. In other scenarios, values are lower than those presented above, reaching less than 300 $m^2$ in $D_1$ for Piazzale Roma and 450 $m^2$ in Santa Marta (Figure 3).

Along with the increase in the bike component, a reduction in alternative modes can be expected. Assuming an unvaried demand, which is the simplest approach, the increase in the number of bikes runs parallel to a contextual reduction in the number of private vehicles, as well as a relief in the use of PT: during morning peak hours, vehicles are mostly overcrowded, resulting in an uncomfortable journey that affects service evaluation form the users' perspective. Yet, more comprehensive simulations about modal split and route assignment are required, to have a more reliable evaluation of the impacts related to other transport modes. Such evaluations are beyond the scope of this contribution and are left as open questions for future research lines.

**Table 6.** Number of bicycles and space needed for parking areas in different scenarios

| Object of analysis | | Status quo ($D_0$ and $S_0$) | | | Biciplan ($D_1$ and $S_1$) | | | SUMP ($D_2$ and $S_2$) | | | Venice like Boston ($D_3$ and $S_3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pl.Roma | S.Marta | Total | Pl.Roma | S.Marta | Total | Pl.Roma | S.Marta | Total | Pl.Roma | S.Marta | Total |
| Bicycles | n | 0 | 0 | 0 | 235 | 353 | 588 | 471 | 706 | 1,177 | 613 | 919 | 1,531 |
| Expected maximum occupancy | n | 0 | 0 | 0 | 165 | 247 | 412 | 329 | 494 | 824 | 429 | 643 | 1,072 |
| Space required | $m^2$ | 0 | 0 | 0 | 297 | 445 | 741 | 593 | 890 | 1,483 | 772 | 1,158 | 1.929 |

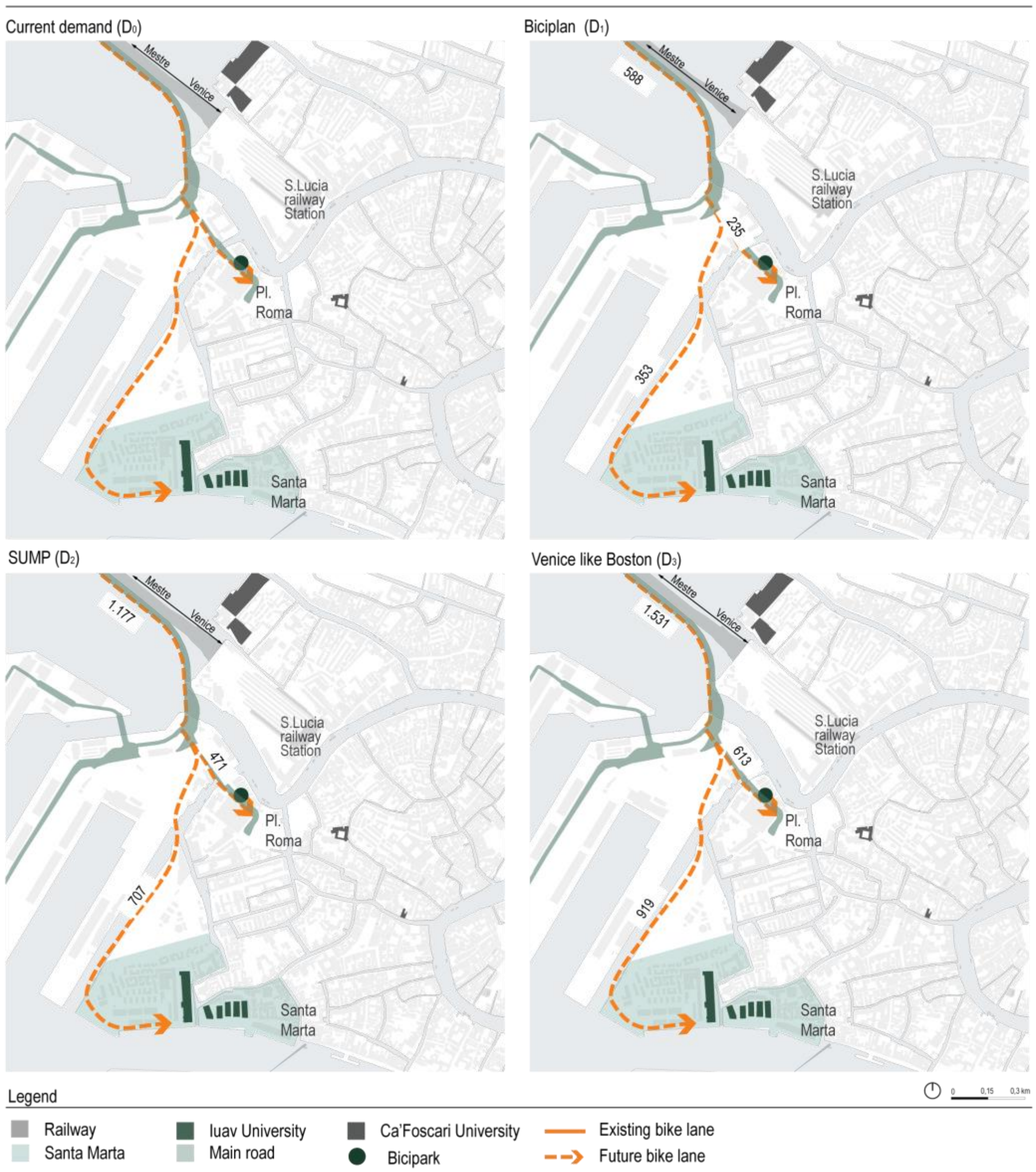


**Figure 3.** Current and future daily bike flows along Liberty bridge to Santa Marta and Piazzale Roma in different scenarios ($D_k$)

## 5 Discussion of results

Historically, the morphological characteristics of Venice affected the relationship between urban planning and transport, with a single road linking the mainland and the historic city and a clear distinction between accessibility and internal mobility. The access to the historic center of Venice suffers from some congestion issues, due to the high volume of private cars and PT that cross the Liberty bridge daily, especially during peak hours. Citizens headed to Venice have to adapt according to the existing options. The recently built cycle lane could be a viable alternative to modify the travel behavior of citizens, especially those who move for working and studying reasons. As emphasized by several authors (see Section 2), direct and safe connections within the destination area are a crucial factor that affects the use of bicycles. Theoretically, the Venetian context is well-suited to fulfil this characteristic, making it a key factor in promoting cycling. Arriving in Venice by bike from the mainland for daily commuters guarantees numerous advantages. Cycling promotes physical well-being, providing an opportunity for healthy physical activity while traveling. It also offers unparalleled freedom in timing, eliminating the constraints of PT schedules. In the Venetian case, two further factors emerge. The first benefit is economic: especially when compared to private road transport, bicycle avoids the high parking costs, which are particularly high (see Section 4). The second aspect concerns the travel safety: the new cycle lane provides a safe and peaceful means for cyclists to reach their destination, without the risk of accidents due to the separation of the cycle lane from the road for the almost totality of the trip.

Despite these positive factors, the cycle path is still a negligible option and also in the future other factors may hinder its bikeability. The presence of infrastructure equipment is one of the factors that can influence the shift from a private vehicle or a PT to cycling. However, it is difficult to promote this shift if users are not provided with adequate solutions. This is what is occurring in Venice: beyond the presence of bicycle lanes, it is crucial to consider the availability of adequate parking facilities. The bicycle parking spaces in Piazzale Roma are expensive and primarily designed for tourists. With such premises, citizens have no incentives to use the cycle path to reach the historic center of Venice, as bike is more expensive than PT. To make cycling accessible to a broader public, it is essential to rethink not only the equipment but also the cost of the service.

This brings attention to a crucial aspect related to travel demand: in all scenarios, we assumed the same travel demand with different modal splits, based on SUMP measurements representing the condition in the year 0. This approach is cautionary but underscores that cycling is not a reliable option. Numerous studies have shown that the availability of parking spaces significantly impacts commuting and cycling for work or study purposes (e.g., Heinen & Buehler, 2019). Policymakers should urgently address this issue to promote cycling as a reliable option for commuting, particularly if the forecasts of $D_3$ are met, where more than 1500 bicycles per day have been estimated. Under the three alternatives that we have indicated, if the city of Venice wants to improve bike mobility to reach the historic center, the current infrastructural layout is insufficient to guarantee such a transition and adequate investments and spaces need to be foreseen. Piazzale Roma, as the main arrival point for the historic center of Venice, requires a radical change in the infrastructural layout. However, limited space and the presence of parking areas for other vehicles represent a constraint not easy to be addressed. In contrast, Santa Marta, conceived as the main node for the university, seems more manageable, given its larger available surface and lower competition with other modes. In parallel with the increase in bike use, a reduction in private vehicles and PT shares may occur. While our scenarios redistributed percentages among alternative modes, a more detailed assessment is necessary, a task that goes beyond the objectives of the analyzed plans and this assessment. Regarding students and academic staff as relevant categories related to systematic mobility, it is important to conduct a more rigorous analysis about their origin. The same holds true for public workers. Yet, one aspect emerges from our scenarios: the bicycle component can potentially divert demand currently using private vehicles and PT, especially during peak hours when vehicular occupancy is critical for commuters, if adequate equipment is given. This is expected to lead to a virtuous circle: indeed, the reduction in traffic pressure may free up space, particularly during morning peak hours, which in turn could be used for bicycle parking facilities.

Enlarging the view to other international contexts, some cases on the promotion of cycling as a sustainable mode can provide further insight into the changes resulting from improved bike systems in the context of systematic commuting. With a focus on universities, some cities among those highlighted in Section 2 represent an interesting benchmark. For instance, Copenhagen and Boston have successfully implemented a cycle-friendly atmosphere on its university campuses, which is fully compatible with the assumptions of the scenario $D_3$. Despite the differences in morphology and urban layouts, these examples may inform the technical and numerical feasibility of proposed quantities. The College of Copenhagen initiated a bike park on its grounds, providing ample space for bikes. Similarly, Boston University, with a significant percentage of residents using cycles for commuting, has implemented cycling amenities on its campus (Boston University, 2023; Vitolo, 2009). These initiatives led to a systematic adoption of bicycles as preferred travel option, which goes beyond the casual and sporadic use. Certainly, the Venetian context is very different and tailored solutions should be proposed. Yet, these international examples highlight the need for physical measures to reclaim space for cycling.

## 6 Conclusion

The use of active transport modes for short-distance trips has become a central focus in various mobility and sectoral plans. Bicycles are increasingly considered as a reliable and sustainable solution that can divert part of the demand from motorized private transport, thus contributing to the reduction of negative transport externalities, particularly those prevalent in urban contexts. In this contribution, we quantified the potential use of bicycles for systematic mobility in the connection between the historic center of Venice and the mainland under different future scenarios. The results presented in Section 4 and discussed in Section 5 yield contradictory findings. On the one hand, the potential catchment area and the limited distances between the two multimodal nodes characterizing the historic center of Venice and the mainland may encourage a shift towards bikes. On the other hand, the lack of infrastructural equipment may pose a challenge to the success of this initiative. These results emphasize that the success of biking cannot overlook the political choices shaping future mobility conditions, as highlighted by relevant international experiences.

The implementation of sustainable mobility plans implies notable constraints, such as budget allocation and policy priorities. Navigating these political challenges with precision is essential to harmonize the interests of diverse stakeholders, here including residents, businesses, and environmental advocates. While forward-thinking initiatives extending beyond mobility concerns might not deliver immediate returns, it is imperative to recognize the enduring impact that they can have over long term, not looking only at the effectiveness as leading paradigm. In places such as Venice, where the cultural dimension significantly shapes the local economy, the promotion of sustainable mobility solutions is not only a pragmatic necessity, but also a crucial aspect of preserving historical and cultural integrity while fostering a more resilient urban environment. In this sense, the historical power of Venice hinged on its physical accessibility over both land and sea. Today, with a radically changed framework, a new form of territorial balance between the historic center and the mainland needs to be sought: the introduction of bicycles for systematic mobility can be seen as an efficient transport mode to reach the city center.

The results presented in this contribution serve only as a starting point for a more in-depth assessment of the implications for future mobility. This may involve both data- and content-related considerations. Notable issues related to data have been discussed in Section 5. As for contents, the potential impacts on other transport modes need thorough evaluations. If bike mobility diverts demand from public transport, micro-mobility, or motorized private mobility, the outcomes may differ, and the impacts of this initiative are to be evaluated very differently. Additionally, the induced demand of bike travelers for non-systematic reasons should be considered, especially given that Venice is a destination on the Munich-Venice long-distance trail, one of the most known international bike routes. Although the provision of new equipment for the cycle network is primarily conceived in support of the systematic trips, such an intervention would have a relevant impact also on tourist-related trips, thus contributing to make the arrivals in the city less dependent on motorized traffic. Incidentally, this is fully in line with the ongoing initiative that seeks to make of Venice the world capital of the sustainability (Venice Sustainability Foundation, 2023). Mobility is one of the pillars of this paradigm, which requires the adoption of adequate and concrete measures to make it more than a simple slogan.

## References

Acharjee, A., & Sarkar, P. P. (2021). Influence of attitude on bicycle users and non-users: A case study of Agartala City, India. *Transportation Research Part D: Transport and Environment, 97*, 102905. https://doi.org/10.1016/j.trd.2021.102905

Agarwal, A., Ziemke, D., & Nagel, K. (2020). Bicycle superhighway: An environmentally sustainable policy for urban transport. *Transportation Research Part A: Policy and Practice*, *137*, 519–540. https://doi.org/10.1016/j.tra.2019.06.015

AVM. S.p.a. (2023). Bicipark Venezia, AVM. Retrieved from https://avm.avmspa.it/it/biciparkvenezia

Bardal, K. G., Gjertsen, A., Reinar, & M. B. (2020). Sustainable mobility: Policy design and implementation in three Norwegian cities. *Transportation Research Part D: Transport and Environment*, *82*, 102330. https://doi.org/10.1016/j.trd.2020.102330

Biciplan. (2020). Dirigente e RUP: Arch. Loris Sartori Biciplan. Retrieved from https://drive.google.com/drive/folders/1C8MwBx8yW6ZiiitS8993_TkGr7hnA1gu

Bosen, J., Fuchte, H. E., & Leicht-Scholten, C. (2023). Cycling to work and making cycling work: What makes committed utility cyclists despite perceived risks of air pollution and traffic? *Journal of Transport & Health*, *28*, 101519. https://doi.org/10.1016/j.jth.2022.101519

Boston University. (2023). Boston University maps campus view. Retrieved from https://maps.bu.edu/?id=647#!ce/36396?ct/36381?s/

Cabral, L., Kim, A. M., & Shirgaokar, M. (2019). Low-stress bicycling connectivity: Assessment of the network build-out in Edmonton, Canada. *Case Studies on Transport Policy*, *7*, 230–238. https://doi.org/10.1016/j.cstp.2019.04.002

Cavallaro, F., & Nocera, S. (2023). Covid-19 effects on transport-related air pollutants: Insights, evaluations, and policy perspectives. *Transport Reviews*. https://doi.org/10.1080/01441647.2023.2225211

Città di Venezia. (2022). *Annuario del turismo dati 2020*. Venice, Italy: City of Venice.

Ek, K., Wårell, L., & Andersson, L. (2021). Motives for walking and cycling when commuting – differences in local contexts and attitudes. *European Transport Research Review*, *13*, 46. https://doi.org/10.1186/s12544-021-00502-5

Eltis. (2023). Presto infrastrutture, parcheggi e depositi per biciclette. Scheda tecnica. Infrastrutture/parcheggi. Retrieved from https://www.eltis.org/sites/default/files/trainingmaterials/12_presto_infrastrutture_parcheggi_e_depositi_per_biciclette_0.pdf

Heinen, E., & Buehler R. (2019) Bicycle parking: A systematic review of scientific literature on parking behavior, parking preferences, and their influence on cycling and travel behavior. *Transport Reviews, 39*(5), 630–656. https://doi.org/10.1080/01441647.2019.1590477

Hidalgo-González, C., Rodríguez-Fernández, M. P., & Pérez-Neira, D. (2022). Energy consumption in university commuting: Barriers, policies, and reduction scenarios in León (Spain). *Transport Policy, 116*, 48–57. https://doi.org/10.1016/j.tranpol.2021.10.016

Istat. (2011). Matrice degli spostamenti 2011.csv. Retrieved from https://www.istat.it/it/archivio/139381

Istat. (2019). Allegato statistico 2019_22_07_2022.xls. Retrieved from https://www.istat.it/it/archivio/275030

IUAV. (2022) Venezia come Boston. Retrieved from https://www.iuav.it/NEWS---SAL/comunicati/2022/Slide-progetto-Venezia-come-Boston.pdf

Johansson, K., Laflamme, L., & Hasselberg, M. (2012). Active commuting to and from school among Swedish children—a national and regional study. *The European Journal of Public Health, 22*, 209–214. https://doi.org/10.1093/eurpub/ckr042

Lanzendorf, M., Scheffler, C., Trost, L., & Werschmöller, S. (2022). Implementing bicycle-friendly transport policies: Examining the effect of an infrastructural intervention on residents' perceived quality of urban life in Frankfurt, Germany. *Case Studies on Transport Policy, 10*, 2476–2485. https://doi.org/10.1016/j.cstp.2022.10.014

Lopes, M., Mélice Dias, A., & Silva, C. (2021). The impact of urban features in cycling potential – A tale of Portuguese cities. *Journal of Transport Geography, 95*, 103149. https://doi.org/10.1016/j.jtrangeo.2021.103149

Luo, J., Boriboonsomsin, K., & Barth, M. (2020). Consideration of exposure to traffic-related air pollution in bicycle route planning. *Journal of Transport & Health, 16*, 100792. https://doi.org/10.1016/j.jth.2019.100792

Ma, L., Ye, R., & Wang, H. (2021). Exploring the causal effects of bicycling for transportation on mental health. *Transportation Research Part D: Transport and Environment, 93*, 102773. https://doi.org/10.1016/j.trd.2021.102773

Ma, X., Yuan, Y., Van Oort, N., & Hoogendoorn, S. (2020). Bike-sharing systems' impact on modal shift: A case study in Delft, the Netherlands. *Journal of Cleaner Production*, *259*, 120846. https://doi.org/10.1016/j.jclepro.2020.120846

Maas, S., Nikolaou, P., Attard, M., & Dimitriou, L. (2021). Examining spatio-temporal trip patterns of bicycle sharing systems in Southern European Island cities. *Research in Transportation Economics, 86*, 100992. https://doi.org/10.1016/j.retrec.2020.100992

Maggi, E., & Vallino, E. (2021). Price-based and motivation-based policies for sustainable urban commuting: An agent-based model. *Research in Transportation Business & Management*, *39*, 100588. https://doi.org/10.1016/j.rtbm.2020.100588

Muenchen-Venezia. (2023). Three countries, three climes and alpine-Mediterranean living environments. Retrieved from https://www.muenchen-venezia.info/en/

Nocera, S., Basso, M., Cavallaro, F. (2017). Micro and macro modelling approach for the assessment of carbon impacts of transport. *Transport Research Procedia 24C*: 146-154.

Orvin, M. M., Fatmi, M. R., & Chowdhury, S. (2021). Taking another look at cycling demand modeling: A comparison between two cities in Canada and New Zealand. *Journal of Transport Geography, 97*, 103220. https://doi.org/10.1016/j.jtrangeo.2021.103220

Poliziani C., Rupi F., Schweizer J., Postorino M.N., Nocera S. (2023). Modeling cyclist behavior using entropy and GPS data. *International Journal of Sustainable Transportation 17*(6): 639–648.

Poorthuis, A., & Zook, M. (2023). Moving the 15-minute city beyond the urban core: The role of accessibility and public transport in the Netherlands. *Journal of Transport Geography*, *110*, 103629. https://doi.org/10.1016/j.jtrangeo.2023.103629

PUM-AV. (2009) Relazione descrittiva. Retrieved from https://portale.comune.venezia.it/utilities/delibereconsiglio/files/2010/DC_2010_40_relazione.pdf

Rérat, P., Haldimann, L., & Widmer, H. (2022). Cycling in the era of Covid-19: The effects of the pandemic and pop-up cycle lanes on cycling practices. *Transportation Research Interdisciplinary Perspectives*, *15*, 100677. https://doi.org/10.1016/j.trip.2022.100677

Ribeiro, P. J. G., Dias, G. J. C., & Mendes, J. F. G. (2022). Health-oriented routes for active mobility. *Journal of Transport & Health*, *26,* 101410. https://doi.org/10.1016/j.jth.2022.101410

Rupprecht S., Brand L., Böhler Baedeker, S., & Brunner, L. M. (2019). *Guidelines for developing and implementing a sustainable urban mobility plan* (2nd ed.). Retrieved from https://www.eltis.org/sites/default/files/sump_guidelines_2019_interactive_document_1.pdf

Saplıoğlu, M., & Aydın, M. M. (2018). Choosing safe and suitable bicycle routes to integrate cycling and public transport systems. *Journal of Transport & Health*, *10,* 236–252. https://doi.org/10.1016/j.jth.2018.05.011

Schneider, F., Jensen, A. F., Daamen, W., & Hoogendoorn, S. (2023). Empirical analysis of cycling distances in three of Europe's most bicycle-friendly regions within an accessibility framework. *International Journal of Sustainable Transportation, 17,* 775–789. https://doi.org/10.1080/15568318.2022.2095945

Stigell, E., & Schantz, P. (2015). Active commuting behaviors in a Nordic metropolitan setting in relation to modality, gender, and health recommendations. *International Journal of Environmental Research and Public Health, 12*, 15626–15648. https://doi.org/10.3390/ijerph121215008

SUMP. (2020a). Piano urbano della mobilità sostenibile di Venezia. Retrieved from https://pums.cittametropolitana.ve.it/pums-adozione-pubblicazione-e-osservazioni/

SUMP. (2020b). *PUMS, relazione descrittiva*. Retrieved from https://www.comune.venezia.it/sites/comune.venezia.it/files/immagini/PUMS/2.1_%20Relazione%20Descrittiva.pdf

Tao, Y., Petrović, A., & Van Ham, M. (2023). Working from home and subjective wellbeing during the COVID-19 pandemic: The role of pre-COVID-19 commuting distance and mode choices. *Journal of Transport Geography, 112,* 103690. https://doi.org/10.1016/j.jtrangeo.2023.103690

Texeira, J. F., Silva, C., Moura, E., & Sá, F. (2023). Factors influencing modal shift to bike sharing: Evidence from a travel survey conducted during COVID-19. *Journal of Transport Geography, 111*, 103651. https://doi.org/10.1016/j.jtrangeo.2023.103651

Vale, D. S., & Pereira, M. (2016). Influence on pedestrian commuting behavior of the built environment surrounding destinations: A structural equations modeling approach. *International Journal of Sustainable Transportation, 10,* 730–741. https://doi.org/10.1080/15568318.2016.1144836

van Essen, H., Van Wijngaarden, L., Schroten, A., Sutter, D., Bieler, C., Maffii, S., ... & El Beyrouty, K. (2019). *Handbook on the external costs of transport* (No. 18.4 K83. 131). Brussels: European Commission.

van Kampen, J., Knapen, L., Pauwels, E., van der Mei, R., & Degundji, E. R. (2021). Bicycle parking in station areas in the Netherlands. *Procedia Computer Science*. https://doi.org/1-s2.0-S1877050921006748

Vendettuoli, G. (2019). *Quanto vale l'economia di Venezia*. Retrieved from https://www.agi.it/economia/venezia_economia-6543585/news/2019-11-14/

Venice Sustainability Foundation. (2023). *An integrated model of sustainable development*. Retrieved from https://vsf.foundation/en/who-we-are/

Vitolo, T. (2009). Yes, parking—for bikes. *BU Today*. Retrieved from https://www.bu.edu/articles/2009/yes-parking-bikes/

Wang, K., Akar, G., Lee, K., & Sanders, M. (2020). Commuting patterns and bicycle level of traffic stress (LTS): Insights from spatially aggregated data in Franklin County, Ohio. *Journal of Transport Geography, 86*, 102751. https://doi.org/10.1016/j.jtrangeo.2020.102751

Wilson, A., & Mitra, R. (2020). Implementing cycling infrastructure in a politicized space: Lessons from Toronto, Canada. *Journal of Transport Geography, 86*, 102760. https://doi.org/10.1016/j.jtrangeo.2020.102760

Wysling, L., & Purves, R. S. (2022). Where to improve cycling infrastructure? Assessing bicycle suitability and bikeability with open data in the city of Paris. *Transportation Research Interdisciplinary Perspectives*, *15*, 100648. https://doi.org/10.1016/j.trip.2022.100648

Yanar, T. (2023). Understanding the choice for sustainable modes of transport in commuting trips with a comparative case study. *Case Studies on Transport Policy, 11*, 100964. https://doi.org/10.1016/j.cstp.2023.100964

Zhao, C., Carstensen, T. A., Nielsen, T. A. S., & Olafsson, A. S. (2018). Bicycle-friendly infrastructure planning in Beijing and Copenhagen — between adapting design solutions and learning local planning cultures. *Journal of Transport Geography, 68*, 149–159. https://doi.org/10.1016/j.jtrangeo.2018.03.003