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Supporting tourism through the promotion of cycling: GIS model applied in the metropolitan area of Cagliari (Italy)

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ABSTRACT

In Italy, where bicycle culture is struggling to catch on, the Extraordinary Plan for Tourism Mobility 2017–22 aims to increase the accessibility of tourist sites through safe and pleasant cycling routes, interconnected with other modes of transport. These same objectives have been pursued by Sardinia, one of the Italian regions more attractive to tourists, through the design of a regional cycle network and a long-distance tourist cycling routes (*Ciclovia della Sardegna*).

The current study focuses on tourism mobility in the metropolitan city of Cagliari, the largest urban area in Sardinia, and aims to explore how much the existing and planned cycling routes constitute an alternative mobility solution for tourists who intend to reach the beaches. In particular, the study aims to evaluate the level of accessibility offered by bicycling to the beaches, which are among the most visited and attractive places for tourists, before and after the implementation of a regional bike tourism network system. A GIS-based procedure was employed and the method comprised of three main steps: (1) data collection and preparation, (2) GIS analysis, and (3) assessment of results. We performed two main types of analysis using GIS. First, we delineated service areas around each beach for various distances. Then, we overlaid and analyzed these areas in conjunction with the accommodation facilities. Second, we measured the accessibility of beaches using a gravity-based accessibility index.

Our results demonstrate that, following the implementation of the regional cycle network Sardinia, various zones in the metropolitan area of Cagliari significantly increased their level of accessibility to the beaches, while others did not. Importantly, the adopted methodology has proven to be a valid tool for assessing cycling accessibility for different infrastructure scenarios.

1. Introduction

The development of travel during the 20th century was crucial in facilitating tourism. To date, tourism represents one of the world's fastest-growing economic sectors as it generates over 10 % of the global GDP (World Tourism Organization and International Transport Forum, 2019), and the tourism industry plays a key role in the economic, social, and cultural development of countries (Manhas et al., 2016). While producing significant benefits in terms of both socioeconomic development and job creation worldwide, tourism also has negative aspects, including the generation of several environmental impacts. Emissions from tourism industry destinations have been steadily growing over the past decades, reaching almost 1,600 million tons of CO_2 in 2016, amounting to 5 % of all energy-related CO_2 emissions (World Tourism Organization and International Transport Forum, 2019). Even if the emissions per passenger have been reduced over the last decades, the growth in the number of tourists has increased so rapidly that it outweighs these improvements by far. The transport of tourists to, from, and around tourist destinations is primarily responsible for the emissions generated by the tourism industry, contributing approximately 75 % of overall emissions (Peeters et al., 2016). Because tourism involves the movement of people (UNWTO, 2020), mobility and tourism are strongly interconnected with mutual growth dynamics, as well as with greenhouse gas emissions.

The negative impacts of tourism have increasingly concerned governments worldwide; consequently, many are striving to hinder tourism's carbon footprint. In addressing these issues, sustainable transport and tourism are closely related and both academics and policy makers at all territorial levels recognized that tourism mobility is highly relevant for the promotion of sustainable mobility. From this perspective,

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promoting cycling can help achieve a sustainable tourism with relevant benefits in terms of environmental, social, and public health. In particular, cycle tourism is considered a valuable opportunity for implementing sustainable tourism and in many parts of the world public investments in bike infrastructure are being made (Rodriguez-Valencia et al., 2021).

Cycling tourists have become increasingly common in many European cities, especially in areas where a deep-rooted local bicycle culture exists, such as Berlin and Copenhagen (Nilsson, 2019). An estimated 2.3 billion cycle tourism jaunts per year in the EU, representing a total economic value of EUR 44 billion and 525,000 jobs (European Parliament, 2012). In Italy, where the bicycle culture is struggling to catch on, cycle tourism accounts for 6.7 % overall tourist demand on average (Legambiente-Isnart, 2024). The Italian Extraordinary Plan for Tourism Mobility 2017–22 aims to increase the accessibility of tourist sites through safe and pleasant cycling routes, interconnected with other modes of transport.

The regional government of Sardinia, one of the Italian regions more attractive to tourists, is pursuing the same objectives through the design of a regional cycle network and a long-distance tourist cycling routes (Ciclovia della Sardegna), which traverses the entire island circularly. The route crosses the regional capital of Cagliari, its historical center, and the main places of tourist and cultural interest in the metropolitan area (Meloni and Palma, 2022). In such a context, where the distances for reaching tourist attractions are quite short, sustainable and active mobility infrastructures, such as cycle paths, can be widely used to explore and move around the city (Mazzulla et al., 2021). At the same time, planning a cycle tourism itinerary in an urban setting requires combining the accessibility of the main tourist attractions with the need to provide intermodal mobility solutions and solving the crossing of complex and fragmented metropolitan territories (Meloni and Palma, 2022).

Furthermore, following the COVID-19 pandemic, the demand for active mobility facilities and infrastructure has increased, as people prefer to spend time outdoors and remain wary of using public transport. In the post-COVID world, Więckowski (2021) points out that for a more sustainable relationship between mobility and tourism, slow tourism and green mobility merge with the concept of proximity. This could enable the transition from the current car-dominated transport system to a "city of proximity" in which it is possible to satisfy one's travel needs with short trips by bicycle.

Despite the close relationship between sustainable transport and tourism, and the well-established concept of accessibility in transportation research (Martellato and Nijkamp, 1998), cycle tourism, which offers a sustainable way to access destinations, has received limited attention in terms of its role in tourist destination mobility and few scientific studies have been conducted on these important correlated topics. Furthermore, existing studies on cycling accessibility primarily focus on access to workplaces and essential neighborhood amenities like parks, grocery stores, healthcare facilities, and schools for local residents (Saghapour *et al.*, 2013; Ospina et al., 2022), while research on accessibility to tourist attractions by bicycle remains scarce (Scappini et al., 2022).

Hence, the current study aims to analyze the above three aspects. Specifically, it focuses on tourism mobility in the metropolitan area of Cagliari, the capital and largest urban area in Sardinia (Italy), and aims to explore how much the existing and planned cycling routes constitute an alternative mobility solution for tourists who intend to visit the beaches. In particular, unlike previous research that focused solely on accessibility for residents, the study evaluates the level of accessibility attained by facilitating bicycle from the coastal municipalities of the metropolitan area to particular touristic points of interest, namely beaches, before and after the implementation of a regional bike tourism network system. The analysis is conducted by employing two different methodologies. First, we traced service areas around the different beaches of the study area for different network distances and quantified the number of beaches that can be reached from each accommodation facility in our study area. Second, we measured the level of accessibility to the beaches from the different areas of the metropolitan area through the computation of a gravity-based accessibility index. The use of a gravity-based accessibility index allows us to evaluate how many other points of interest can be reached from each point of interest using either the existing or planned cycle network. This evaluation, unlike that carried out using service areas, takes into account that reaching a specific point becomes physically more tiring depending on the distance range (Páez et al., 2012).

The remainder of the paper is organized as follows. Section 2 presents a review of past literature about cycle-tourism and cycle accessibility (Section 2). Section 3 provides a description of the study context. Section 4 describes the methodology, while empirical results are reported in Section 5. Policy implications and key conclusions are drawn in section 6.

2. Literature review

Tourism is an important driver of socioeconomic growth, yet it also puts a strain on resources and the transport network. The last decade has witnessed a plethora of studies investigating human mobility patterns; however, the mobility of tourists often remains underexplored. Various studies focus on the impacts of tourism mobility on the transport system and environment and/or tourism promotion as a tool for sustainable mobility. Focusing on three back casting scenarios, and using techniques integrating quantitative and qualitative elements, Dubois et al. (2011) discuss options for emission reductions in the tourism sector and the consequences of mitigation for global tourism-related mobility by 2050. Gühnemann et al. (2021) assess the current state of knowledge on the complex relationship between tourism travel and climate change for the case study of Austria. Cavallaro et al. (2017) focus on the impacts of mass-tourism mobility on the transport system of a prototypal Mediterranean coastal city and attempt to assess the impact of different soft and hard measures that can facilitate the decongestion of tourist traffic.

In the context of tourism mobility, another important point is that cycling promotion can help to achieve a sustainable tourism with relevant benefits in terms of environmental, social and public health. Two main goals can be achieved by investing financial resources into the construction of bike infrastructures: 1) contributing to build a sustainable transportation system by promoting urban cycling as an alternative transport mode for fulfilling different tasks in an urban area and reaching activity destinations; 2) promoting cycling culture and increasing the bike infrastructures represents a direct benefit for cycling tourists (Mazzulla et al., 2021). However, while the relationship between transport and tourism has been a subject of discussion in the literature, most studies have focused solely on evaluating transport as simply a means of transport rather than as a contextual component of the tourism supply, especially at destinations. Cycle tourism is a booming sector with an increasing number of tourists every year.

Zhu (2022) formulates the cycle-tourist route-planning problem: in order to maximize cycle-tourists' utility of visiting points of interest (POI), minimize the total travel time, maximize the Bicycle Level of Service (BLOS), and minimize the number of intersections on the cycling routes taken (subject to monetary and time budget, *etc.*). Pantelaki et al. (2023) use a latent class analysis to identify three groups of people with segmented preferences for bike tourism experiences, including destinations, accommodations, and multimodal behaviors. Weed et al. (2014) perform a *meta*-analysis involving bike tourists classified by distance travelled and overnight stays, resulting in seven types of cycling groups: (a) far "holidayers", (b) near "holidayers", (c) cycle tourers, (d) far day trippers, (e) near day trippers, (f) far residents, and (g) near residents. Lumsdon (2000) evaluated the concept of a planned sustainable transport network, the National Cycle Network in the UK, as a potential model for the integration of transport, tourism, and recreation.

The accessibility to a touristic attraction is affected by the quality of the transport networks used to reach it (Brabyn and Skelly, 2002). The positive correlation between cycle infrastructure and the growth of cycle tourism is widely addressed in the literature (Moscarelli, 2019), while the same cannot be said for accessibility. A transport system can be considered sustainable if it is accessible, safe, environmentally friendly, and affordable (Richardson, 2005). Few previous works on cycling accessibility focus only on access to peripheral or rural areas, employment, and/or neighborhood facilities such as parks, grocery stores, health services, and schools (Wieckowski, 2021; Kesarovski and Hernández-Palacio, 2023; Ospina et al., 2022). Kesarovski and Hernández-Palacio (2023) focus on accessibility to grocery shops, an essential urban service, in the Stavanger metropolitan area (Norway) using 10 min isochrones for walking and cycling. Coppola et al. (2020) propose a methodology to identify the tourist areas that present a gap in accessibility, and to assess the most appropriate type of investments (infrastructure or services) to improve sustainable tourist accessibility.

Hull et al. (2012) observe that, in some cases, accessibility measures are too complex, abstract, and hard to comprehend and interpret, and that accessibility indicators, even though founded on strong methodological basis, must remain sufficiently simple and intuitively meaningful to be used by professional and public administrations in their application.

Considering all these aspects, in our analysis is we employed an easy to implement GIS-based approach to measure the level of accessibility achieved by traveling by bicycle to particular points of interest for tourists, namely beaches, before and after the implementation of a regional bike tourism network system. The innovative aspect lies in the fact that we compared the data of accessibility of the attractor/generator poles before and after the intervention, so as to verify the areas in which tourists' needs could be satisfied with short and safe cycling trips.

3. Study context

The metropolitan city of Cagliari is the largest urban area in Sardinia (Italy), an island in the Mediterranean Sea. It extends over the southern coast of the island, and hosts approximately half a million inhabitants.

Given the object of the paper, our study area will include only the coastal municipalities of the metropolitan area of Cagliari: Cagliari, Capoterra, Maracalagonis, Pula, Quartu Sant'Elena, Sarroch, Sinnai, Villa San Pietro (Fig. 1). Tourism is one of the biggest industries of the area, with its historical venues, recreational beaches, and coastline. Because of the presence of the airport, train station, and harbor, the municipality of Cagliari can be considered the main traffic hub of the area. Furthermore, cruise ships regularly visit the old port of Cagliari. In 2023, according to the observatory of the Region of Sardinia,[1] in the examined area, tourist presence data reveal a significant influx, with 511,201 arrivals and a total presence of 1,660,395 individuals (average stay duration is 3.25 nights). Notably, summer accounts for 57.77 % of these arrivals, indicating a seasonal peak in tourism. It is also worth noting that according to the Touristic Plan of Sardinia,[2] in Sardinia as a whole, tourism expenditure in 2022 amounted to approximately €1.24 million. In terms of the relationship between accommodation facilities and bicycle services in the area under study, due the lack of official datasets concerning this topic, a research on the Booking.com portal was conducted. This revealed that 10.59 % of accommodations offer bicycle excursions, while 10.00 % provide bicycle rental services. According to the Italian business register,[3] there are seventeen companies with that provide bicycle rental services in the area under exam. Despite the presence of bicycle rental companies, there has been no bike sharing service in Cagliari since July 2023, while some scooter sharing companies operate there. From a survey conducted by the authors in 2023 among tourists at the Cagliari airport, the mode choice of tourists visiting the metropolitan area of Cagliari reflects a preference for car travel, with 78.8 % opting for car rental, car sharing, or personal vehicles. Public transport is utilized by 26.0 % of tourists, while only 1.0 % utilized a bike. According to data published in the Sardinian Cycling Plan,[4] approximately 20,000 cyclists choose a cycling holiday in Sardinia annually by purchasing packages from local and foreign tour operators.

For the accessibility analysis of the current paper, we examined the trips from the centroids of the census zones of the coastal municipalities of the metropolitan city of Cagliari. Census zones are the smallest geographical unit made available by the Italian Statistical (ISTAT). In our analysis, we included only the census zones characterized by the presence of residential building and/or accommodation facilities. Another type of origin we consider in our analysis are the different accommodation facilities of the metropolitan area. Specifically, we considered all the hotels, holiday residences and apartments, retirement villages, bed and breakfasts, hostels, and camping grounds listed in the regional register of accommodation facilities of Sardinia (204 accommodation facilities).

Concerning destinations, we evaluated the accessibility to the beaches from the metropolitan city of Cagliari (Fig. 1), which are among the most visited and attractive places to tourists. More specifically, we included in the analysis all the beaches (28 beaches) listed in the Regional Landscape Plan of Sardinia (Zoppi and Lai, 2010), which can be considered as the most important from a naturalistic viewpoint. The beaches we considered included natural urban beaches, as well as rural beaches that often lack facilities like changing rooms, showers, and bars. Fig. 1 shows the distribution of the beaches across the territory of the entire metropolitan area.

In terms of the supply side (Fig. 2), we consider two different scenarios. In the base scenario, the network comprises road segments that can be considered safe for those who decide to travel by bicycle. In the future scenario, the base scenario's network is integrated with the regional bike tourism network of Sardinia (Scappini et al., 2022). The main aim of the network is to promote of cycling mobility for both recreational and utilitarian purposes. The intervention involves the implementation of the following structural measures: network of routes, facilities for cyclists, intermodal hubs, specialized signs, and cycle parks. In the area of our interest the cycle network will extend for 127.4 km and connect all seven municipalities of the metropolitan city of Cagliari. Tourists' access to the cycling network will be guaranteed by the connection with the airport, the commercial port, the railway station, and the stops of the urban and *trans*-urban public transport network of Sardinia.

4. Methodology

In this study, a GIS-based procedure was employed to evaluate the level of accessibility by bicycle to particular points of interest before and after the implementation of a regional bike tourism network system. The method consists of three main steps: 1) data collection and preparation, 2) GIS analysis, and 3) assessment of results.

In the first phase, we collected and prepared the data useful for our analysis. The study involved the use of different types of datasets from different sources. Specifically, census data were extracted from the Italian National Institute for Statistic (ISTAT), while network data, Points of Interest (POI) data, and accommodation facilities data derive from the Region of Sardinia land information system. The reader should note that, as discussed in the previous section, the POI of our analysis comprise the urban and rural beaches of the metropolitan area of Cagliari.

1 https://osservatorio.sardegnaturismo.it/it/open-data.

2 https://delibere.regione.sardegna.it/protected/68798/0/def/ref/DBR68454/.

3 https://www.registroimprese.it/.

4 https://www.regione.sardegna.it/documenti/1_38_20190222150647.pdf.

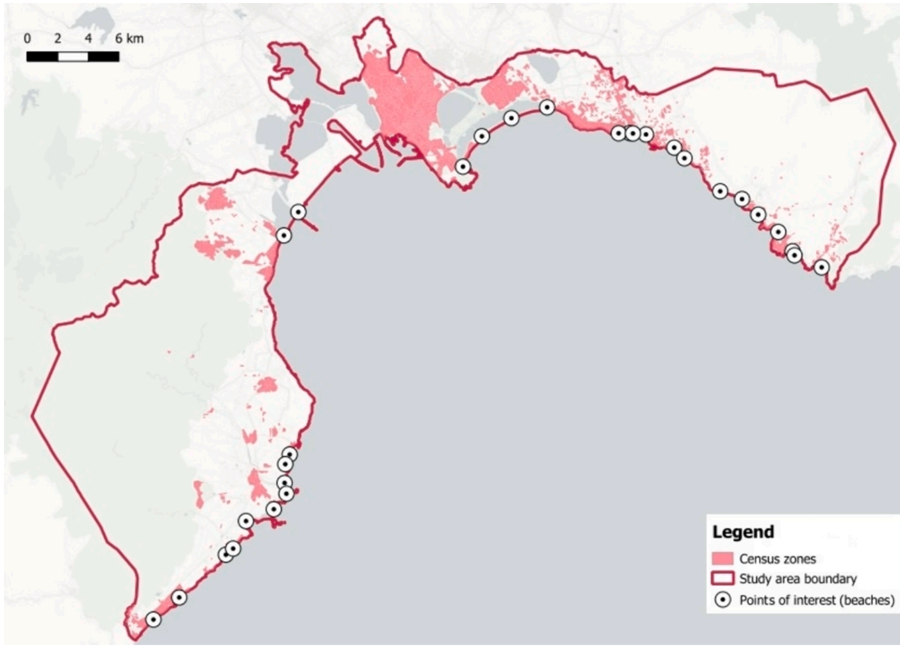

Fig. 1. Distribution of points of interest.

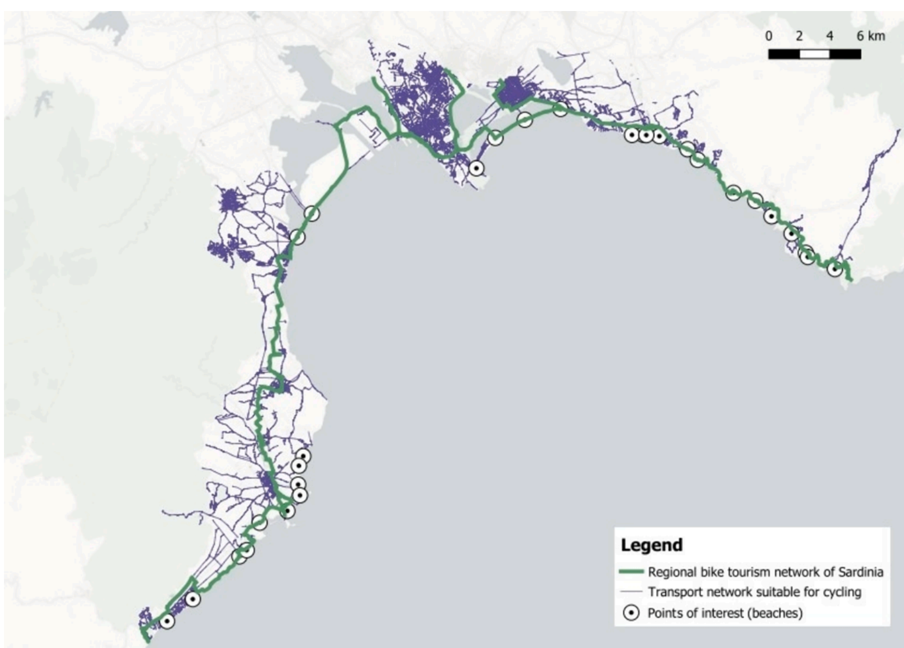

Fig. 2. Distribution of points of interest.

An important operation of the data preparation step was the modification of the transport network within the study area, so that each road segment included in the network could be considered suitable for the use of a bicycle. However, a network based only on cycling lanes and paths is inappropriate as it would lack interconnectivity. Hence, as suggested by Kesarovski and Hernández-Palacio (2023), our cycling network was constructed by removing all the segments that cannot be used by cyclists from the whole transport network of the study area. More specifically, we removed: 1) all road segments where cycling is forbidden (motorways and trunk roads), 2) high-speed urban roads, and 3) road segments characterized by the presence of intersections and overpasses where cycling would be highly dangerous.

The second step of the work was implemented through QGIS software. We conducted two different types of analysis:

- Computing service areas around the different Points of Interest (POI) for different distances and combining them with the accommodation facilities of the study area
- Measuring the accessibility of POI through a gravity-based accessibility method

For the first type of analysis, for each POI and different travel distances, we traced a service area for the current situation and the scenario encompassing the building of the regional network of Sardinia. In our case, a service area is defined as the portion of the network that can be reached within a distance starting from a POI. Then, through a spatial join operation, it was possible to evaluate the number of POI reachable from each accommodation facility. The threshold distances for the computation of the service areas were 2 km, 5 km and 10 km. We defined 2 km as the average acceptable travel distance for cycling reported in literature (Rahul and Verma, 2014; Tsunoda et al., 2021). At this distance, people typically experience minimal discomfort when cycling. We chose 5 km because past studies suggest it is an average cycling distance for non-commuting purposes (Mundet and Coenders, 2010; McNeil, 2011; Donaire-Gonzalez et al., 2015). Finally, 10 km was selected because the literature indicates that the vast majority of cycling trips fall within this range (Mundet and Coenders, 2010; Rupi and Schweizer, 2018).

In the second type of analysis for each origin we computed a gravity-based accessibility measure. Equation (1) is a general version of this type of measure (Geurs and Van Wee, 2004; Vale and Pereira, 2017):

$$A_i = \sum_{j=1}^{N} O_j \delta(C_{ij}) \tag{1}$$

where A_i is the accessibility to a set of destination from zone i, O_j is the number of opportunities j, C_{ij} is the cost of travelling from i to j, $\delta(C_{ij})$ is the cost function, also defined as the impedance function, applied to the cost C_{ij}. C_{ij} is the travel distance from i to j. We chose to use travel distance instead of travel time because cycling speed depends on different factors (individual characteristic of the cyclist, the type of bike used, terrain gradient, level of car traffic of the roads, *etc.*): assigning a travel speed on the basis of these characteristics without having any observed data available, but relying solely on hypotheses made by us, could lead us to misinterpret the results of our analysis. Another important element to highlight is the fact that our model does not take into account the terrain gradient, a factor that may hinder people from using a bike. Nevertheless, given the scope of the paper, namely the analysis of the accessibility of the different areas of the metropolitan city of Cagliari before and after the implementation of the regional cycling network of Sardinia, because this structural measure does not involve a change of the slopes of the different cycling paths, not including this factor in the accessibility analysis does not distort our results.

For the specific case of our study, the impedance function takes the form of a cumulative-Gaussian function (Vale and Pereira, 2017):

$$\begin{cases} \delta(C_{ij}) = 1, for\, C_{ij} \le a \\ \delta(C_{ij}) = \exp\left(-\frac{(C_{ij}-a)^2}{\nu}\right), \; for\, C_{ij} > a \end{cases} \tag{2}$$

where a is the threshold parameters reflecting the acceptable cycling distance, and ν is a parameter that represents the slope of the curve after that initial distance. The parameters for a and ν were established in the following way. The threshold a was set to 2 km because, as mentioned earlier, this is generally considered a comfortable travel distance for cycling. The coefficient ν was set to 12.987. This ensures that the impedance function takes the value 0.50 when the cycling distance is equal to 5 km and approaches 0 for a distance of 10 km (Fig. 3). The rationale for using 5 km and 10 km is the same as that used for the service areas.

We evaluated the accessibility to POI in the metropolitan city of Cagliari before (base scenario) and after the implementation of the regional cycling network of Sardinia (future scenario).

5. Results

In this section we present the results of the GIS analysis. We first focus on the results achieved through the computation of service areas. Figs. 4 and 5 illustrate an example of the visual outcome of our analysis: we reported the number of beaches that each accommodation facility can access by cycling 5 km in both the base and future scenarios (see Fig. 6).

Apart from visual representation, we reported the results of the first type of GIS analysis in Table 1, where we present the share of accommodation facilities from which a certain number of beaches can be reached via a different cycling distance for the whole study area and for the different municipalities. In general, the analysis indicates that in the base scenario only 25.0 % of the total accommodation facilities have access to at least one beach within 2 km, 73.1 % within 5 km, and 95.2 % within 10 km.

In the future scenario, the share of accommodation facilities that can reach a beach increases to 27.4 % in the case of a service area of 2 km, to 75.5 % in the case of a service area of 5 km, and to 97.6 % in the case of a service area of 10 km. It is also interesting to note that the percentage of accommodation facilities from which three or more beaches can be reached by cycling within a distance of 5 km rises to 29.4 % in the future scenario from 22.1 % in the base scenario. No differences were detected for the service area of 2 km. The analysis of the results at the locality

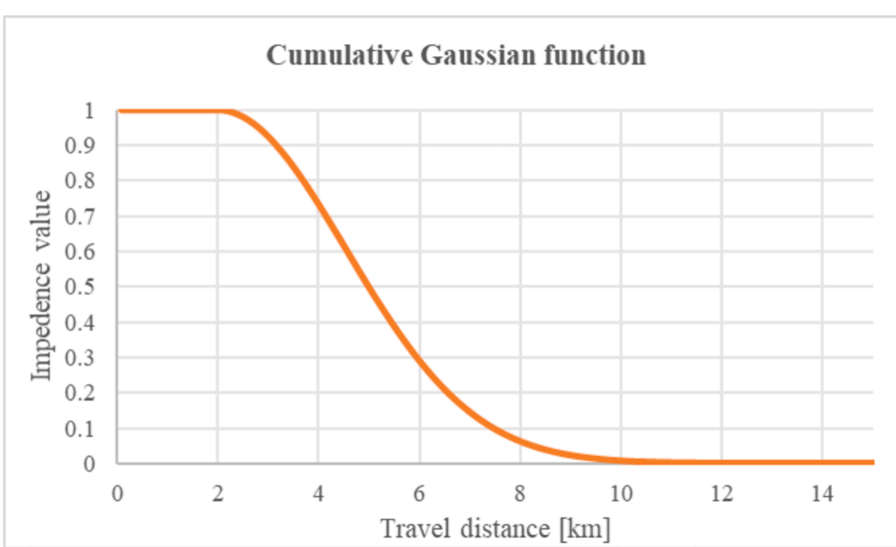

Fig. 3. Cumulative Gaussian function.

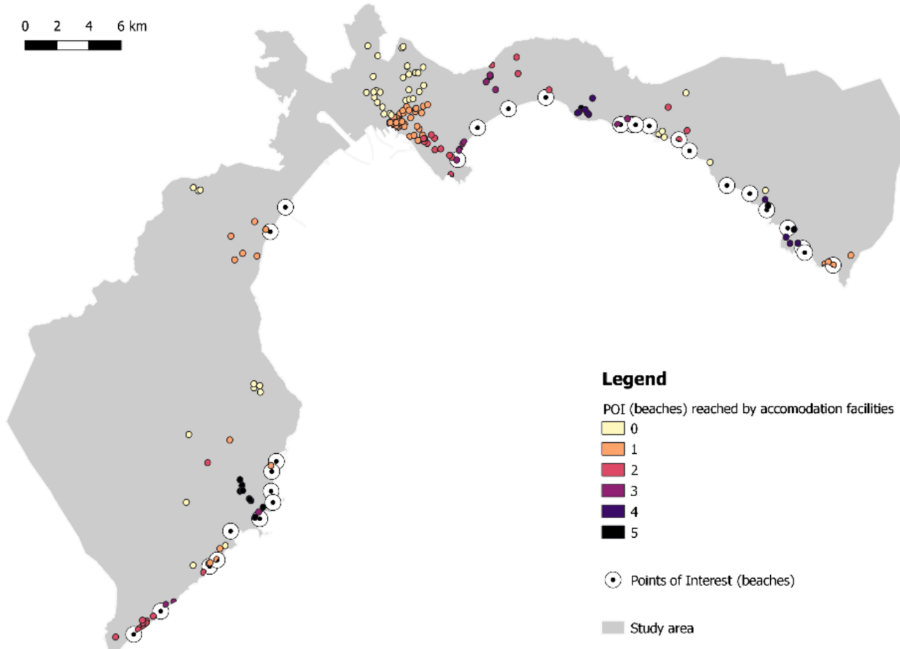

Fig. 4. Number of beaches that each accommodation facility can access by cycling 5 km in the base scenario.

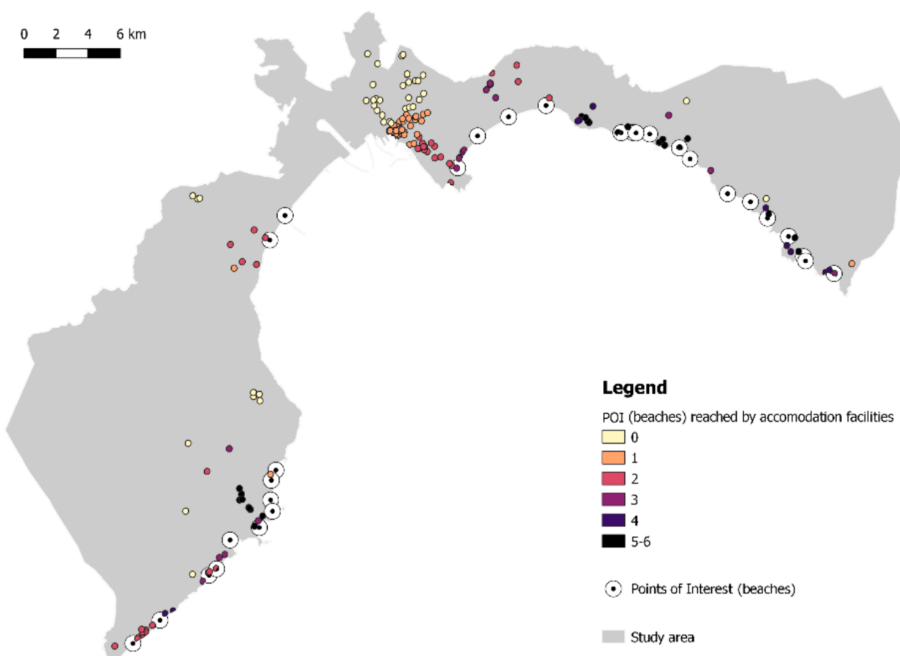

Fig. 5. Number of beaches that each accommodation facility can access by cycling 5 km in the future scenario.

level reveals the existence of considerable variations among the different municipalities. In fact, it can be observed that benefits linked to the implementation of the regional cycling network are especially strong in the municipalities of Quartu Sant'Elena, Pula, and Sinnai. In particular, for the municipality of Quartu Sant'Elena, we observed that there would be an increase of 57.7 % (from 21.9 % to 34.4 %) in the number of hotels, hostels, camping grounds, and retirement villages having access to at least one beach after the construction of the regional cycling network.

We now turn our attention to the results of the comprehensive accessibility analysis. Table 2 and Fig. 3 provide descriptive statistics related to the accessibility index in the base and future scenarios. It can be seen that the average value of the accessibility index increases from 1.080 in the base scenario to 1.358 in the future scenario, while the median rises from 1.163 in the base scenario to 1.461 in the future scenario. It is also possible to compute the weighted mean, where the value of accessibility of each census zone is weighted by the dimension of each zone. The value of weighted mean of the accessibility is equal to 1.377 in the current situation, and 1.784 in the future scenario. The value of the accessibility index is characterized by a sizable variability among the different municipalities. Indeed, some municipalities, like Cagliari and Capoterra, are characterized by a low level of average accessibility both in the base scenario and future scenario.

Per previous literature (Saghapour et al., 2017; Chen et al., 2020),

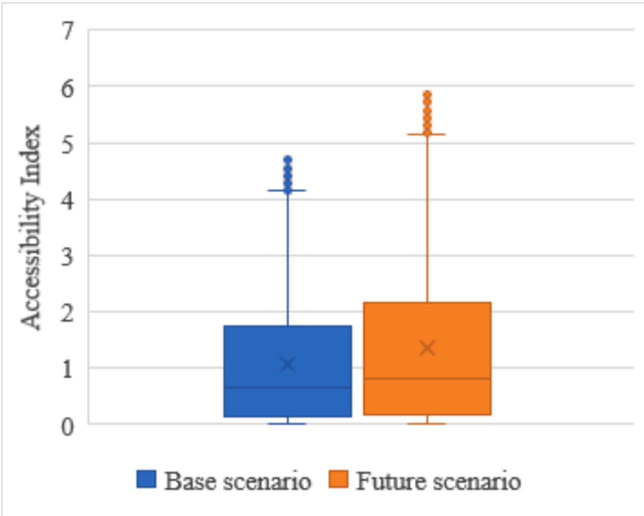

Fig. 6. Accessibility index for the base and future scenarios.

we employed quantile classification to cluster accessibility in classes: after excluding 0 values, five accessibility levels were identified. Figs. 7 and 8 represent the levels of accessibility for the whole study area and how they would change following the implementation of the regional cycling network of Sardinia. Specifically, Fig. 7 illustrates the accessibility to beaches in the base scenario, while the map in Fig. 8 reveals accessibility to the beaches in the future scenario. In particular, the analysis of Fig. 8 indicates that the census zones located in the right side of the maps (municipalities of Quartu Sant'Elena and Sinnai) have the biggest advantage of the implementation of the cycling network. This is can be attributed to the fact that currently these areas are segregated from the rest of the territory due to the presence of a trunk road (SP17) that, despite its landscape value, is considered unsafe by cyclists because of its particular layout and its high traffic volume during summer. Hence, the implementation of a safe cycling path would permit tourists staying in this area to easily reach many more beaches. A similar situation can be observed for various districts in the municipality of Pula, in the left corner of the map. Also, in this case the presence of a motorway (SS195) prohibits tourists in these zones to safely cycle to certain beaches. If we turn our attention to the census zones of municipality of Cagliari, it can be noted that most are characterized by a poor level of accessibility both in the base and future scenarios. This is because some of these zones, especially those located in the suburbs, can reach only the urban beach of the city (Poetto beach) within a 10 km distance, suggesting that the main problem here is their geographical position and not the cycling network.

Table 3 presents the number and share of census zones belonging to the different levels of accessibility in each municipality of the study area in both scenarios. Overall, the number of census zones characterized by a null value of accessibility decreases from 127 to 75 (−2.2 %), while the number of zones with an excellent level of accessibility rise to 399 from 266 (+6.3 %) in the future scenario. Results in Table 3 confirm what we determined from our previous analysis: the municipalities of Pula, Quartu Sant'Elena, and Sinnai would achieve the greatest benefits in terms of accessibility to the local beaches in the scenario involving the construction of the regional cycling network. Instead, as previously discussed, although the municipality of Cagliari is the largest in terms of extension and population in Sardinia, the level of accessibility of its census zones does not change that much: what stands out is the fact that the share of census zones with a good and excellent level of accessibility only increases from 9.5 % to 12.5 %.

Finally, it is important to note that the use of bicycles to reach beaches should not be limited to tourists. Indeed, the local residents, as well as tourists, are among the potential beneficiaries of a higher level of accessibility to the coastal areas and beaches. For this reason, Table 4 provides the number and share of residents of the metropolitan area of Cagliari for each accessibility category and for the different municipalities.

Table 1
Share of accommodation facilities from which a certain number of beaches can be reached via different cycling distances before and after the implementation of the Regional Bike Tourism Network of Sardinia.

Municipality	Distance	0 beaches		1 beach		2 beaches		3 beaches		>3 beaches	
		Base scenario	Future scenario	Base scenario	Future scenario	Base scenario	Future scenario	Base scenario	Future scenario	Base scenario	Future scenario
Metropolitan city of Cagliari (Total)	2 km	75.0 %	72.6 %	13.0 %	12.0 %	9.6 %	13.0 %	2.4 %	2.4 %	0.0 %	0.0 %
	5 km	26.9 %	24.5 %	36.5 %	27.4 %	14.4 %	18.8 %	9.1 %	10.6 %	13.0 %	18.8 %
	10 km	4.8 %	2.4 %	8.7 %	4.8 %	13.0 %	10.1 %	40.4 %	32.2 %	33.2 %	50.5 %
Cagliari	2 km	91.5 %	91.5 %	4.7 %	4.7 %	3.8 %	3.8 %	0.0 %	0.0 %	0.0 %	0.0 %
	5 km	30.2 %	30.2 %	54.7 %	50.9 %	10.4 %	14.2 %	4.7 %	4.7 %	0.0 %	0.0 %
	10 km	0.9 %	0.9 %	1.9 %	0.9 %	14.2 %	10.4 %	64.2 %	63.2 %	18.9 %	24.5 %
Capoterra	2 km	80.0 %	80.0 %	20.0 %	20.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	5 km	40.0 %	40.0 %	60.0 %	10.0 %	0.0 %	50.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	10 km	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Maracalagonis	2 km	0.0 %	0.0 %	0.0 %	0.0 %	50.0 %	50.0 %	50.0 %	50.0 %	0.0 %	0.0 %
	5 km	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	100.0 %
	10 km	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	100.0 %
Pula	2 km	37.8 %	35.1 %	32.4 %	24.3 %	29.7 %	40.5 %	0.0 %	0.0 %	0.0 %	0.0 %
	5 km	8.1 %	5.4 %	13.5 %	0.0 %	32.4 %	40.5 %	8.1 %	10.8 %	37.8 %	43.2 %
	10 km	5.4 %	2.7 %	5.4 %	0.0 %	0.0 %	0.0 %	43.2 %	0.0 %	45.9 %	97.3 %
Quartu Sant'Elena	2 km	78.1 %	65.6 %	6.3 %	9.4 %	9.4 %	18.8 %	6.3 %	6.3 %	0.0 %	0.0 %
	5 km	18.8 %	6.3 %	0.0 %	0.0 %	21.9 %	12.5 %	34.4 %	34.4 %	25.0 %	46.9 %
	10 km	18.8 %	6.3 %	0.0 %	0.0 %	6.3 %	0.0 %	0.0 %	0.0 %	75.0 %	93.8 %
Sarroch	2 km	85.7 %	85.7 %	14.3 %	14.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	5 km	85.7 %	85.7 %	14.3 %	14.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	10 km	0.0 %	0.0 %	85.7 %	85.7 %	0.0 %	0.0 %	0.0 %	0.0 %	14.3 %	14.3 %
Sinnai	2 km	0.0 %	0.0 %	83.3 %	83.3 %	0.0 %	0.0 %	16.7 %	16.7 %	0.0 %	0.0 %
	5 km	0.0 %	0.0 %	83.3 %	16.7 %	0.0 %	0.0 %	0.0 %	16.7 %	16.7 %	66.7 %
	10 km	0.0 %	0.0 %	83.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	16.7 %	100.0 %
Villa San Pietro	2 km	100.0 %	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	5 km	50.0 %	50.0 %	50.0 %	0.0 %	0.0 %	0.0 %	0.0 %	50.0 %	0.0 %	0.0 %
	10 km	50.0 %	50.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	50.0 %	50.0 %

Table 2
Descriptive statistics of accessibility index.

Municipality		Base Scenario	Future scenario	Difference
Metropolitan city of Cagliari (Total)	Mean	1.080	1.358	0.278***
	Weighted mean	1.377	1.784	0.407
	Median	1.163	1.461	0.298
	Standard Deviation	0.657	0.801	n/a
	Lower	0.000	0.000	0.000
	Upper	4.771	5.927	1.156
	Number of zones	2,397	2,397	n/a
Cagliari	Mean	0.613	0.666	0.052**
	Weighted mean	0.503	0.545	0.043
	Median	0.356	0.388	0.033
	Standard Deviation	0.660	0.694	n/a
	Lower	0.000	0.000	0.000
	Upper	3.233	3.265	0.032
	Number of zones	1,391	1,391	n/a
Capoterra	Mean	0.444	0.618	0.174***
	Weighted mean	0.486	0.742	0.257
	Median	0.324	0.367	0.043
	Standard Deviation	0.325	0.543	n/a
	Lower	0.000	0.033	0.033
	Upper	1.210	1.962	0.752
	Number of zones	173	173	n/a
Maracalagonis	Mean	2.964	3.089	0.125
	Weighted mean	3.873	4.127	0.254
	Median	4.327	4.533	0.206
	Standard Deviation	2.038	2.128	n/a
	Lower	0.000	0.000	0.000
	Upper	4.694	4.920	0.226
	Number of zones	44	44	n/a
Pula	Mean	2.625	2.964	0.339**
	Weighted mean	2.662	2.895	0.232
	Median	2.553	2.899	0.346
	Standard Deviation	1.405	1.352	n/a
	Lower	0.000	0.498	0.498
	Upper	4.771	5.033	0.262
	Number of zones	134	134	n/a
Quartu Sant'Elena	Mean	2.166	3.099	0.933***
	Weighted mean	2.445	3.536	1.091
	Median	2.397	2.938	0.541
	Standard Deviation	1.147	1.483	n/a
	Lower	0.000	0.000	0.000
	Upper	4.161	5.927	1.766
	Number of zones	470	470	n/a
Sarroch	Mean	0.509	0.578	0.070
	Weighted mean	0.532	0.588	0.056
	Median	0.126	0.153	0.027
	Standard Deviation	0.549	0.612	n/a
	Lower	0.000	0.000	0.000
	Upper	1.615	1.932	0.317
	Number of zones	100	100	n/a
Sinnai	Mean	1.178	2.163	0.985***
	Weighted mean	1.483	2.632	1.149
	Median	0.988	1.957	0.968
	Standard Deviation	1.063	1.250	n/a
	Lower	0.000	0.000	0.000
	Upper	4.265	4.737	0.472
	Number of zones	57	57	n/a
Villa San Pietro	Mean	1.536	1.910	0.373*
	Weighted mean	1.739	2.068	0.329
	Median	1.837	2.262	0.425
	Standard Deviation	0.704	0.906	n/a
	Lower	0.172	0.191	0.018
	Upper	2.253	2.768	0.514
	Number of zones	27	27	n/a

Note: * Statistically significant at 90 % **Statistically significant at 95 % *** Statistically significant at 99 %

It is possible to observe, that in the base scenario, null accessibility is estimated for 1.6 % of residents, while very poor and poor accessibility is estimated for 52.9 %. Conversely, in the future scenario, the share of the total population ranging from null to poor accessibility drops to 48.4 %. If we turn our attention to the municipality of Cagliari, only 12.3 % of its population would have a good–excellent level of accessibility to the local beaches.

6. Conclusions

The number of cycle tourism trips has been steadily increasing in Europe and, at the same time, various projects aimed at developing long distance cycle networks and routes have been financed across the continent. Nevertheless, the planning of a cycle network at a regional level across a diverse array of urban and metropolitan areas is a complex task that is far from straightforward, as the interconnection of strategic points of different itineraries, both from a touristic and transportation standpoint, must be guaranteed. Hence, evaluating accessibility to specific spatial points for different alternative infrastructure scenarios and from a quantitative standpoint is of special interest for transport planners and policy-makers. This would permit them to define and implement policies, strategies and measures to accommodate cycle-tourists' needs and requirements.

Despite existing research exploring cycling accessibility and proposing various methodologies (e.g., gravity-based models) to measure it, there is a lack of studies and case studies on how these methods can be applied to assess the impact of regional cycle-tourism networks on access to activities and services by bicycle. This gap in knowledge motivates our study, which adopts a GIS approach to investigate whether the implementation of the regional cycling network in the metropolitan area of Cagliari (Italy) could be a valid alternative for tourists and locals to enjoy easier beach access by bicycle.

To reach our goal, we adopted two different methodologies. First, through the computation of service areas, we analyzed how many beaches, popular tourist destinations, could be reached by bike via different travel distances employing as a starting point the accommodation facilities of the study area. Although this method is easy to use, it does not consider the fact that travelers perceive increasing travel distances in different ways. This is why in the second part of the work, as suggested by Vale *et al.* (34), for each census zone of the metropolitan area of Cagliari we computed a gravity-based accessibility index which assumes that the cyclist starts feeling the effects of the travel distance only after 2 km.

Two important and correlated results need to be highlighted. First of all, we observe that various coastal areas, especially those in the

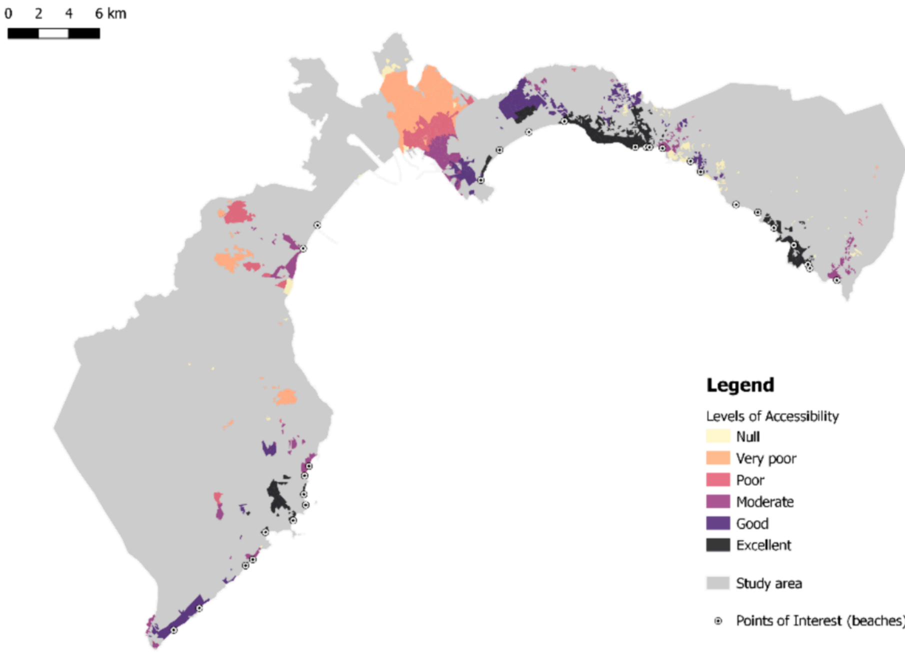

Fig. 7. Level of Accessibility to the beaches in the base scenario.

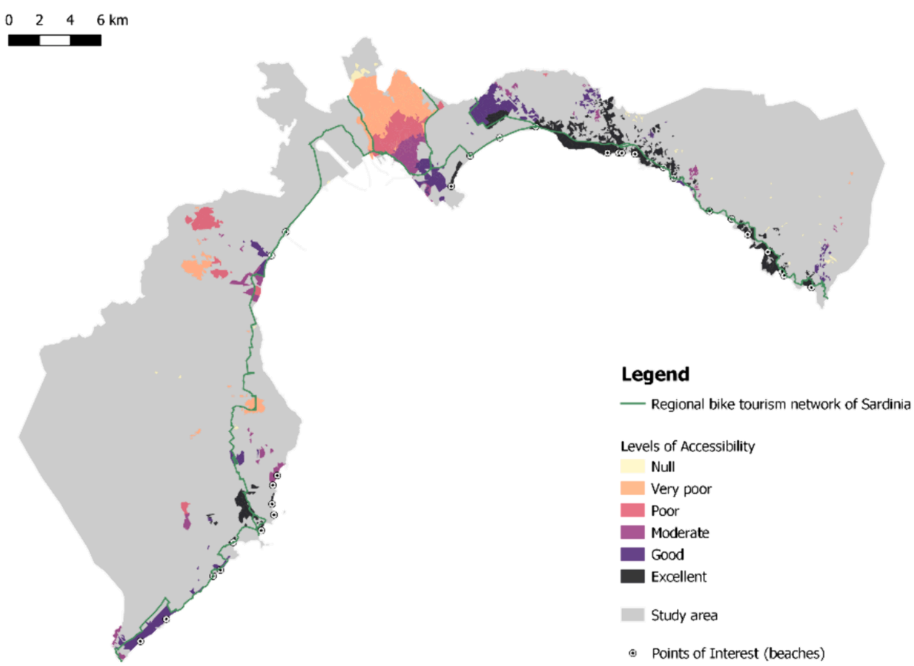

Fig. 8. Level Accessibility to the beaches in the future scenario.

territories of Quartu Sant'Elena, Sinnai, and Maracalagonis, thanks to the regional cycling network, have easy access to the beaches as the network breaks down the access barriers of the existent infrastructural network. The same does not occur for the areas further inland. This point is an important outcome because it confirms the need to guarantee an integrated supply system that ensures the possibility of traveling by bike in integration with public transport. Next, a long distance from the origin to the nearest point of the cycling network could be a disadvantage to traveling by bike. Municipalities such as Quartu Sant'Elena or Pula are close to the network and their access to the beaches is guaranteed, while it is not the same for most of the internal areas.

From these results, some policy implications for local municipalities and the regional government who will be planning and implementing a regional cycling tourism network can be formulated. Accessibility can be improved by densifying and expanding the network at a regional level, rather than at the level of individual municipalities. This is because tourist points of interest (POIs) are spread across the region, not concentrated in any single territory. Hence, strong collaboration among administrations is essential for achieving this and all involved partners need to reach a consensus on the optimal route for the network. At the same time, it is important to consider the relationship between transportation and land use. While the existence of a cycle network surely improves the level of accessibility, longer distances can still lead to lower accessibility levels. Therefore, to encourage cycling demand in

Table 3
Level of accessibility to the beaches of the metropolitan area of Cagliari for the census areas of the different municipalities.

	Accessibility categories	Accessibility ranges	Base Scenario		Future scenario	
			N	%	N	%
Total	Null	0.00	127	5.3 %	75	3.1 %
	Very poor	0.00–0.29	759	33.1 %	728	31.2 %
	Poor	0.30–0.79	461	21.4 %	393	17.7 %
	Moderate	0.80–1.64	414	19.9 %	397	18.6 %
	Good	1.65–2.79	369	19.5 %	404	20.0 %
	Excellent	≥ 2.80	266	16.3 %	399	22.6 %
Cagliari	Null	0.00	21	1.5 %	16	1.2 %
	Very poor	0.00–0.29	628	45.1 %	609	43.8 %
	Poor	0.30–0.79	385	27.7 %	312	22.4 %
	Moderate	0.80–1.64	226	16.2 %	280	20.1 %
	Good	1.65–2.79	108	7.8 %	149	10.7 %
	Excellent	≥ 2.80	23	1.7 %	25	1.8 %
Capoterra	Null	0.00	4	2.3 %	0	0.0 %
	Very poor	0.00–0.29	73	42.2 %	58	33.5 %
	Poor	0.30–0.79	63	36.4 %	73	42.2 %
	Moderate	0.80–1.64	33	19.1 %	26	15.0 %
	Good	1.65–2.79	0	0.0 %	16	9.2 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %
Maracalagonis	Null	0.00	10	22.7 %	10	22.7 %
	Very poor	0.00–0.29	4	9.1 %	4	9.1 %
	Poor	0.30–0.79	0	0.0 %	0	0.0 %
	Moderate	0.80–1.64	0	0.0 %	0	0.0 %
	Good	1.65–2.79	0	0.0 %	0	0.0 %
	Excellent	≥ 2.80	30	68.2 %	30	68.2 %
Pula	Null	0.00	3	2.2 %	0	0.0 %
	Very poor	0.00–0.29	0	0.0 %	0	0.0 %
	Poor	0.30–0.79	1	0.7 %	1	0.7 %
	Moderate	0.80–1.64	40	29.9 %	28	20.9 %
	Good	1.65–2.79	35	26.1 %	34	25.4 %
	Excellent	≥ 2.80	55	41.0 %	71	53.0 %
Quartu Sant'Elena	Null	0.00	70	14.9 %	30	6.4 %
	Very poor	0.00–0.29	2	0.4 %	6	1.3 %
	Poor	0.30–0.79	3	0.6 %	2	0.4 %
	Moderate	0.80–1.64	38	8.1 %	23	4.9 %
	Good	1.65–2.79	206	43.8 %	152	32.3 %
	Excellent	≥ 2.80	151	32.1 %	257	54.7 %
Sarroch	Null	0.00	13	13.0 %	13	13.0 %
	Very poor	0.00–0.29	45	45.0 %	45	45.0 %
	Poor	0.30–0.79	4	4.0 %	3	3.0 %
	Moderate	0.80–1.64	38	38.0 %	34	34.0 %
	Good	1.65–2.79	0	0.0 %	5	5.0 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %
Sinnai	Null	0.00	6	10.5 %	6	10.5 %
	Very poor	0.00–0.29	1	1.8 %	0	0.0 %
	Poor	0.30–0.79	5	8.8 %	2	3.5 %
	Moderate	0.80–1.64	38	66.7 %	6	10.5 %
	Good	1.65–2.79	0	0.0 %	27	47.4 %
	Excellent	≥ 2.80	7	12.3 %	16	28.1 %
Villa San Pietro	Null	0.00	0	0.0 %	0	0.0 %
	Very poor	0.00–0.29	6	22.2 %	6	22.2 %
	Poor	0.30–0.79	0	0.0 %	0	0.0 %
	Moderate	0.80–1.64	1	3.7 %	0	0.0 %
	Good	1.65–2.79	20	74.1 %	21	77.8 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %

inland areas, the network should be planned to facilitate intermodality by passing by major public transport stops. In this way, accessibility equality among tourists is promoted, given that regardless of their chosen accommodation (whether expensive but close to tourist points of interest or more affordable options further from these points), all tourists can enjoy a similar level of access to beaches through the cycling network.

While the specific results of our research cannot be generalized to other contexts, given the peculiar characteristics of the study area and of the POIs, the proposed methodology can be applied to other contexts for the assessment of cycling accessibility. Our approach, which employs both the analysis of service areas for various distances and the computation of a gravity-based accessibility index, is user-friendly and flexible enough to be adopted by planners for the assessment of regional cycling networks in other touristic areas. Indeed, though some modifications and adaptations can be made, such as the identification of different normative distances for defining service areas, adjustments to the impedance function of the accessibility index, or the type of origins and destinations taken into consideration, the basic principles of the methodology remain valid.

Our work has some limitations. First, in the analysis, the slopes and travel time by bike along the cycling regional network were not taken into account. The methodology used in this paper allows us to consider the distance or travel time; we chose to take into account the distance because it is a uniquely defined characteristic. Instead, travel time, as well as the effort required when cycling along routes characterized by steep slopes, depends on individuals' speed which in turn depends on individual physical characteristics (age, gender, body mass index), the bicycle type (muscular vs e-bike, racing bike vs gravel bike vs mountain bike), weather conditions, and so on. Second, for the specific case of our

Table 4
Level of accessibility to the beaches of the metropolitan area of Cagliari for the population of the different municipalities.

	Accessibility categories	Accessibility ranges	Base Scenario		Future scenario	
			Pop [N]	Pop [%]	Pop [N]	Pop [%]
Total	Null	0.00	4,067	1.6 %	870	0.3 %
	Very poor	0.00–0.29	76,039	30.1 %	73,920	28.9 %
	Poor	0.30–0.79	55,784	22.8 %	47,788	19.2 %
	Moderate	0.80–1.64	36,095	15.6 %	35,366	15.0 %
	Good	1.65–2.79	59,000	26.5 %	66,633	29.0 %
	Excellent	≥ 2.80	25,295	14.5 %	31,703	17.6 %
Cagliari	Null	0.00	298	0.2 %	272	0.2 %
	Very poor	0.00–0.29	68,281	45.6 %	67,266	45.0 %
	Poor	0.30–0.79	43,032	28.8 %	34,900	23.3 %
	Moderate	0.80–1.64	26,921	18.0 %	28,747	19.2 %
	Good	1.65–2.79	10,470	7.0 %	17,718	11.8 %
	Excellent	≥ 2.80	576	0.4 %	675	0.5 %
Capoterra	Null	0.00	1,356	5.8 %	0	0.0 %
	Very poor	0.00–0.29	3,436	14.7 %	2,328	10.0 %
	Poor	0.30–0.79	12,585	54.0 %	12,792	54.9 %
	Moderate	0.80–1.64	5,937	25.5 %	4,474	19.2 %
	Good	1.65–2.79	0	0.0 %	3,720	16.0 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %
Maracalagonis	Null	0.00	25	9.9 %	25	9.9 %
	Very poor	0.00–0.29	0	0.0 %	0	0.0 %
	Poor	0.30–0.79	0	0.0 %	0	0.0 %
	Moderate	0.80–1.64	0	0.0 %	0	0.0 %
	Good	1.65–2.79	0	0.0 %	0	0.0 %
	Excellent	≥ 2.80	228	90.1 %	228	90.1 %
Pula	Null	0.00	5	0.1 %	0	0.0 %
	Very poor	0.00–0.29	0	0.0 %	0	0.0 %
	Poor	0.30–0.79	0	0.0 %	0	0.0 %
	Moderate	0.80–1.64	370	5.3 %	209	3.0 %
	Good	1.65–2.79	805	11.5 %	902	12.9 %
	Excellent	≥ 2.80	5,814	83.1 %	5,883	84.1 %
Quartu Sant'Elena	Null	0.00	2,179	3.2 %	369	0.5 %
	Very poor	0.00–0.29	10	0.0 %	15	0.0 %
	Poor	0.30–0.79	142	0.2 %	90	0.1 %
	Moderate	0.80–1.64	1,820	2.7 %	1,271	1.9 %
	Good	1.65–2.79	45,787	66.8 %	42,264	61.6 %
	Excellent	≥ 2.80	18,638	27.2 %	24,567	35.8 %
Sarroch	Null	0.00	198	3.9 %	198	3.9 %
	Very poor	0.00–0.29	4,231	82.4 %	4,231	82.4 %
	Poor	0.30–0.79	20	0.4 %	4	0.1 %
	Moderate	0.80–1.64	688	13.4 %	659	12.8 %
	Good	1.65–2.79	0	0.0 %	45	0.9 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %
Sinnai	Null	0.00	6	1.5 %	6	1.5 %
	Very poor	0.00–0.29	1	0.2 %	0	0.0 %
	Poor	0.30–0.79	5	1.2 %	2	0.5 %
	Moderate	0.80–1.64	358	87.5 %	6	1.5 %
	Good	1.65–2.79	0	0.0 %	45	11.0 %
	Excellent	≥ 2.80	39	9.5 %	350	85.6 %
Villa San Pietro	Null	0.00	0	0.0 %	0	0.0 %
	Very poor	0.00–0.29	80	4.0 %	80	4.0 %
	Poor	0.30–0.79	0	0.0 %	0	0.0 %
	Moderate	0.80–1.64	1	0.0 %	0	0.0 %
	Good	1.65–2.79	1,938	96.0 %	1,939	96.0 %
	Excellent	≥ 2.80	0	0.0 %	0	0.0 %

work, we measured cycling accessibility considering only the beaches of the metropolitan area as points of interest, given their high level of attractiveness to tourists. However, the adopted methodology can be employed to compute the level of accessibility to other types of points of interest, such as places of artistic, historical, and archaeological interest (*e.g.*, museums, churches, historic buildings) or areas of great naturalistic importance (*e.g.*, parks).

Future research can further refine the proposed methodology. The impedance function of the accessibility index could be expanded to consider the quality of cycling infrastructure along routes (e.g., dedicated bike paths vs. mixed traffic). Additionally, as mentioned above, accessibility and the threshold of distance can vary depending on individual characteristics. Future research could explore incorporating this aspect into the impedance function.

CRediT authorship contribution statement

Francesco Piras: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Eleonora Sottile:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Italo Meloni:** Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

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

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