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The regional cycle network of Sardinia: upgrading the accessibility of rural areas through a comprehensive island-wide cycle network

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Abstract

Context: Cycling is a climate-friendly means of transport that enables people to reduce their use of motorized transport and makes human settlements more inclusive and resilient. In Italy, the development of cycling has recently been boosted by the approval of Law no. 2/2018, which makes it compulsory for all Italian regions to draw up a regional cycling mobility plan.

Objective: To meet this regulatory provision, the Region of Sardinia approved the Regional Plan for Cycling Mobility in December 2018. Drawn up by the Sardinian Regional Transport Agency and the transportation research group of the University of Cagliari, the plan aims to lay out a regional cycle network to promote the use of the bicycle as a means of transport for both every day and tourist–recreational needs. One of the main objectives of the plan is to make the inland areas of the island more accessible, as the development of such areas tends to have been neglected compared to the coastal areas linked to seaside tourism. Hence, the plan intends to contribute to the increase of tourist flows into rural areas, which can be a strategic segment of local development.

Results: By analysing the methodology adopted to lay out Sardinia's regional cycle network, the aim of the current paper is to show how the planning of an integrated cycle network in an island context can improve sustainable mobility and accessibility in the rural areas through which it passes. Furthermore, our analysis indicates that many rural settlements along the routes of the planned cycle network are sufficiently near each other for people to travel between them by bicycle.

Conclusions: Therefore, the cycling infrastructure could prompt a sustainable increase in the accessibility and connectivity of inland areas and stimulate the formation of clusters of small, interconnected towns and villages.

Keywords: Accessibility, Rural areas, Sustainable mobility, Cycle network, Cycle tourism, Local development

1 Introduction

In the context of sustainable development strategies, cycling is recognized as one of the forms of mobility best able to bring economic, social, and environmental benefits at both individual and community level [11]. In recent years, these positive effects have contributed to cycling being assigned an increasingly important role in sustainable mobility policies, with a growing body of research and technical papers published on how to create cycling systems in urban areas. However, there is very little knowledge of how cycling can be planned for low-density territories and rural areas [21].

Although there is no commonly agreed definition of rural areas at a European level, the term usually refers to

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regions with a population density of below 150 inhabitants per km^2. Using the population density scale, at a regional level, the Organisation for Economic Co-operation and Development (OECD) classifies almost 56% of EU territory as rural regions; at local level, this percentage reaches 83% and involves about 30% of Europe's population [25].

Therefore, the question of sustainable mobility in relation to the accessibility of rural areas must be addressed if we want to ensure equal opportunities for a substantial portion of the population. To date, rural mobility has received far less attention from policy-makers than urban mobility; hence, few mobility solutions have been generated. Due to the decline in the quality and quantity of local services, people living in rural areas have become increasingly dependent on connections with larger urban centres and reliant on the use of private cars. This phenomenon has resulted in the current need for better-designed and more sustainable regional public policies on rural mobility [5].

Investment in the development of cycling infrastructure must be placed at the heart of rural development initiatives to address the poor connectivity among rural areas and nearby destinations, such as urban centres.

Another reason to invest in cycling infrastructure is that doing so generates impacts on the territory in the form of tourism flows [35]. In many European countries, cycle tourism is an important part of active tourism, often along highly appealing single routes or a cycle network infrastructure. Furthermore, cycling networks for tourism include itineraries that, in many cases, run through both urban and rural areas. This spread of routes can be an important lever to encourage bike use, even in daily journeys between nearby settlements, because of the short distances between them.

This paper specifically discusses the case of Sardinia, a largely rural Italian island. The region's cycle network was developed between 2016 and 2018 by the Sardinian Regional Transport Agency, drawing on the expertise of our research group, within the Interuniversity Centre for Economic Research and Mobility of the University of Cagliari.

There are two primary aims of this study. First, by studying the case of Sardinia, we explore the possibility of increasing the accessibility of rural areas by planning a regional cycle network. Retracing the planning methodology of Sardinia's cycle network enables us to analyse how this type of network, planned to ease commuting and leisure mobility by cycling, integrated with other means of transport and supported by adequate facilities, can be a valid regional policy to guarantee access to rural areas and stimulate local development through new economic initiatives, such as those related to cycle tourism.

Second, we evaluate the performance of the cycle network of Sardinia by comparing it with that planned in the region of Piedmont, in northern Italy, with the specific aim of understanding whether the methodological approach we adopted achieves a better result.

The remainder of the paper is organized as follows. In Sect. 1.1 we draw a general framework about the approaches over cycle network planning. In Sect. 2, we describe the Sardinian setting, showing how the regional cycling mobility plan fits into this context (2.1), and explain the methodology adopted to plan the regional cycle network (2.2). In Sect. 3, we report the planning results obtained and illustrate the network's potential to connect rural areas. In Sect. 4, after having drawn a general picture of the Piedmont cycle network, we report the analysis and the results of the comparison. A discussion and key conclusions are presented in Sect. 5.

1.1 Literature review

Over the past 2 decades, the importance of planning cycling infrastructure as a network has been highlighted by both local governments and planning agencies [32] as well as from the academic field [2, 17, 27]. For example, Buehler & Dill [2] reported the correlation between the development of extensive networks of separate bicycle facilities and high cycling levels in countries and cities of Western Europe and North America; the Federal Highway Administration [12] recognized that only complete, or almost seamless, direct and safe cycle networks create a perception of sufficient comfort and accessibility that will motivate people to use them to access to key destinations or neighbouring communities.

However cycle network planning has traditionally been viewed from an urban design point of view, rather than a rural or regional planning perspective [1]. On the other hand, it is generally at the regional level that long-distance cycle routes are developed, usually as a part of regional policies like those related to rural development [3].

Although extensive research has been carried out on the planning of urban cycling networks, the scientific literature on the methodological approach employed to plan regional cycling networks is relatively scarce. Wałdykowski et al. [34] pointed out that a systemic approach is rarely considered when planning cycling networks, as they are most often considered as one of the tasks included in the general transport infrastructure development plan, and their construction is seen as a long-term incremental process. Krizek and Roland [17] studied bike networks in relation to the importance that the discontinuities may have on their use, though they did not propose any method for network planning considering this issue. Mattuone et al. [22] suggested the need to refer to the grey literature (design standards, reports, handbooks and guides) published from government offices and civil organizations [3, 6, 14, 19, 23].

Generally, in the planning of cycle networks, the key elements are identified in nodes and links [2]. Concerning the identification of the nodes, CROW [6] establishes that the first step of this process is the selection of the most important origins and destinations, which depend on the size of the study area. The areas of origin are usually the main city centres and residential places, railway stations and other mobility hubs, while the destinations are all those services, activities and structures that can attract cyclists as well as leisure and tourist attractions. The cohesion of the cycling network with the public transport network (railway stations and bus stops) plays an important role [6]. Cycle tourists often use public transport to get to the starting point and come back from the ending point of a route. Therefore, a regional cycling network should be planned considering the public transport access points, their infrastructure and available connections [3].

Concerning the definition of the links, Gallagher and Parking [14] identify two essential stages in the mapping of (1) the existing routes and facilities and (2) the options for the development and improvement of the network, including any additional links that are not part of the routes but that could potentially be used by cycle traffic. In the development of a cycling network CROW [6] identifies five key requirements that must be met by all links of the network: cohesion, directness, safety, comfort and attractiveness. In selecting the ideal infrastructures for the development of the cycling network, routes along local roads or corridors outside the road network (riverbanks, railways) might be more comfortable and even more direct for some connections. Routes that make use of non-public roads—for example agricultural, forest, industrial or water management—include advantages like low gradients and the limited number of crossings with road network [3].

In the European panorama, it is possible to trace some interesting examples of cycle routes and networks at national and regional level which have been designed to promote sustainable mobility in rural areas. One of these is the Spanish programme Vías Verdes, which emerged in the nineties with the aim of recovering the disused infrastructure that crossed rural territories (railways, historic roads, canal service roads) and turning it into non-motorized routes. To date, this initiative has recovered more than 2700 km of greenways and turned them into 125 routes across the nation, which have proved to be excellent resources to promote mobility and encourage the creation of local employment and the establishment of the population in rural areas [20].

Turning to cycling planning at the regional level, one interesting example is the regional cycle network of Western Pomerania (Poland), built in the five years since the adoption of the concept plan in 2014. The network consists of 800 km of high-quality cycle paths, of which 350 km of new, dedicated cycle paths are already open or under construction. This network was developed with an eye to the degree of current development, touristic attractiveness, and need for socioeconomic revitalisation. Most of the network covers existing infrastructure but the construction of new cycle tracks was needed to ensure the routes were high-quality.

Among the key points of this experience, Buczynski [1] highlights that it is essential to assign the role of leader to a regional administration in order to focus regional priorities and guide local experiences, avoiding fragmentation and benefiting from economies of scale.

Although Italy still lacks a national strategy and action plan, in the last few years an important boost to the development of cycling has been given at the legislative level. First, in 2017, the adoption of Directive No. 375/2017 aimed to put in place a national cycle tourism system consisting of ten tourist cycle routes; then, in 2018, Law no. 2/2018 on the development of cycling mobility was passed. This law promotes the use of bicycles as a means of transport for both daily use and tourist activities and recognizes their importance in improving the territory and its assets. Moreover, it requires all Italian regions to draw up and approve a Regional Cycling Mobility Plan (Art. 5), addressed to the creation of rural cycle routes.

Currently, regional planning for cycling in Italy is a fragmented and ongoing process. Only seven regions (Lombardy, Emilia Romagna, Piedmont, Tuscany, Veneto, and Sardinia) have addressed the issue of regional cycling mobility in either a dedicated plan or within a wider infrastructure and mobility plan. Both types of plan aim to affirm the bicycle as a mobility alternative in urban and extra-urban areas and lay out a regional cycle network. For three regions (Friuli Venezia Giulia, Liguria, and Puglia), the planning process required by the aforementioned law is underway; however, other regions are developing territorial cycle networks without any proper planning tool.

The evidence reviewed here seems to suggest a lack in the scientific literature of a theoretical and consistent methodological approach for the planning of regional cycling networks, as only grey literature's materials provide general information on the approach to be adopted in planning cycling infrastructures. In this sense, the current work intends to contribute to cycling research by introducing a new planning methodology for cycling networks in rural areas and applying it in the Sardinian context. Based on a reticular approach, the cycle network of Sardinia is defined with a GIS-based multi-stage process that allowed us to identify the main nodes and connections on the regional territory. Through a comprehensive island-wide network, rural areas are connected to each other's and with the main urban poles, so as to reduce the marginalization of smaller centres and avoid the formation of a few major centres of attraction.

To validate our results, we make a comparison with a different case study of the Italian context, namely Piedmont, chosen among the regions that have already planned a regional cycle network. Although it is not an island and belongs to the more developed context of northern Italy, Piedmont has characteristics similar to Sardinia in terms of geographic extension and the presence of rural areas. This allowed us to make a direct comparison of the performances achieved by each network in increasing the accessibility of these areas.

On the other hand, it is important to stress that its proximity to other Italian regions and European states crossed by cycling routes has represented for Piedmont an important boost in the development of cycling infrastructures. Indeed, the main aim of the first planning process of the regional cycle network was to satisfy the crossing of the itineraries at the transregional and transnational levels.

2 Material and methods

2.1 The Sardinian setting

Sardinia is characterized by an interesting dualism: the island plays an important role in the tourism sector but, at the same time, a significant portion of the region is somewhat marginalised. With an area of about 24,100 km^2 and a population of 1.6 million inhabitants, Sardinia has a population density of 69 persons per km^2. The territory is divided into 377 municipalities, of which 31.6% have no more than 1000 inhabitants.

Using the OECD parameter mentioned before to classify rural areas through population density, Sardinia is defined as a "predominantly rural region": only the capital, Cagliari, is classified as an urban area (A), while 10 municipalities are classified as rural areas with intensive and specialized agriculture (B), 71 as intermediate rural areas (C), and 295 as rural areas with development problems (D). These last areas include a total population of 827,044 inhabitants, corresponding to approximately half the island's total (Fig. 1).

When compared with the Italian mainland, the fact that Sardinia is an island is the first intrinsic feature to put it at a disadvantage: it suffers from limited accessibility, isolation, and a limited range of small businesses, all of which contribute to its continuous depopulation [10]. Consequently, 250 of the 377 municipalities have experienced population decline in recent years. In addition to migratory flows away from the island, these demographic problems are connected to the movement of the population from villages to cities and from inland areas to the coast. This has led, over the years, to a major regional imbalance in population density which continues to be fuelled by the dominant role played by coastal tourism in Sardinia.

Tourism is among the activities which drives the Sardinian economy. However, the seasonality of tourist flows, which are heaviest in summer, is still a major issue for the economic development of the region. Despite the variety of touristic experiences on offer and the potential yet to be realized from other types of tourism, Sardinia is currently perceived as a seaside destination. A comparison with its main international competitors, namely Malta and the Balearics, shows that for Sardinia to become less dependent on seaside tourism requires a diversification of the tourist activities on offer, in particular to include more outdoor activities, such as boating, hiking, and cycling, and activities related to the island's cultural heritage [13].

From a geographical point of view, more than 80% of the island territory consists of hills or mountains. This situation has historically discouraged cycling, except in smallish areas with flat terrain. On the other hand, one factor which might help the development of cycling mobility in Sardinia is its mild climate nearly all year round, which strongly influences the use of bicycles for recreational purposes [8]. However, it is, above all, due to the almost total lack of cycling infrastructure that no cycling culture has been created in Sardinia and cycling remains a marginal mode of transport, largely used for leisure and sport: in 2019, 1.36% of the Sardinian population commuted by bicycle, while 41.6% used it for any purpose [16].

Over the past few years, local authorities have been showing increasing interest in cycling mobility. Cycle paths in Sardinia increased from 20.4 to 81.9 km between 2011 and 2016 [28]. However, many of the actions implemented focused merely on infrastructure, which remains largely discontinuous, disconnected, and mainly concentrated in urban areas.

2.2 The methodological approach to planning the regional cycle network

International experiences and best practices show that a cycling mobility system, whether oriented towards daily travel or tourism, requires the application of a coordinated and integrated set of complementary interventions, actions, and measures. In this sense, the planning methodology of the cycle network of Sardinia used a systemic approach based on the combination of two different

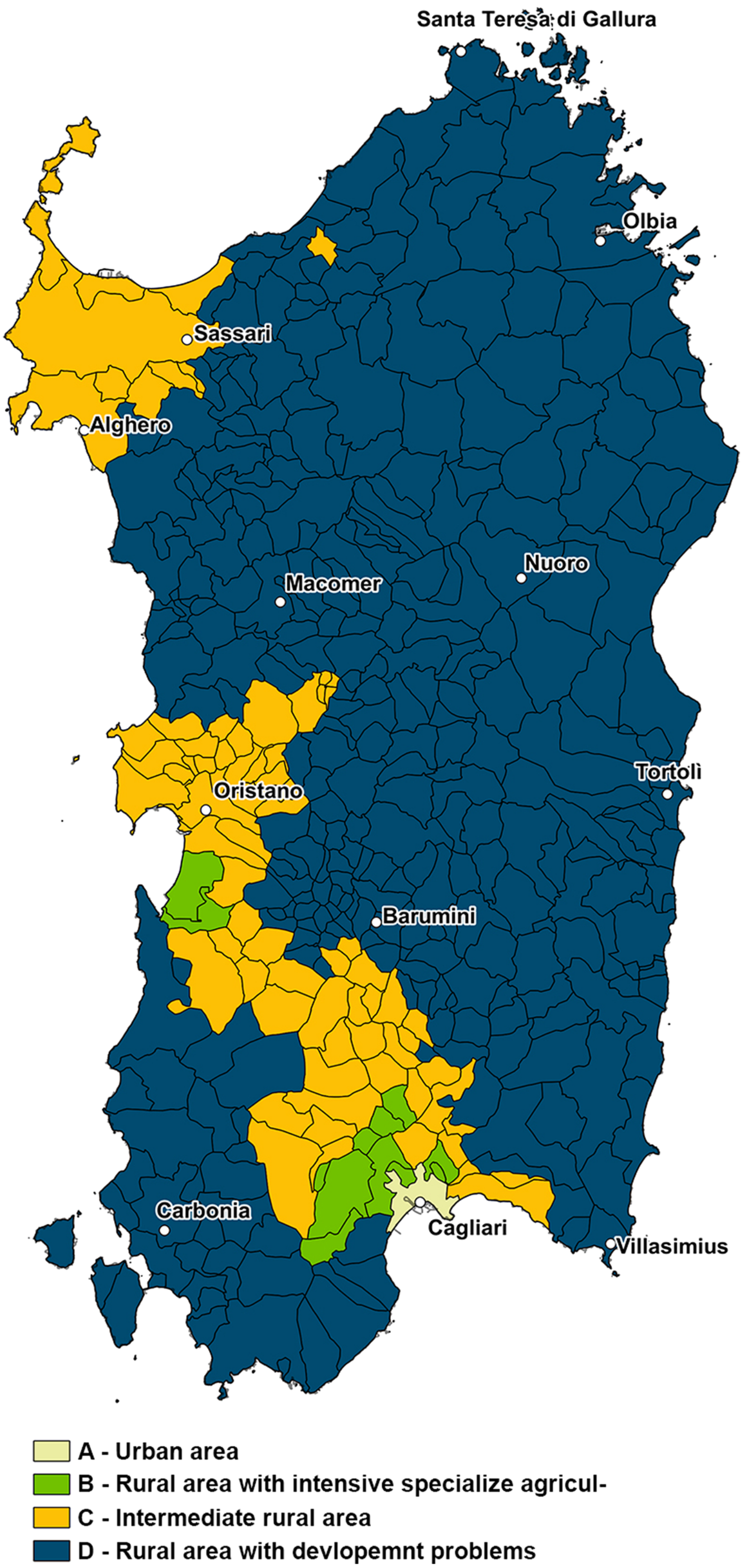

Fig. 1 Types of municipalities according to the OECD classification

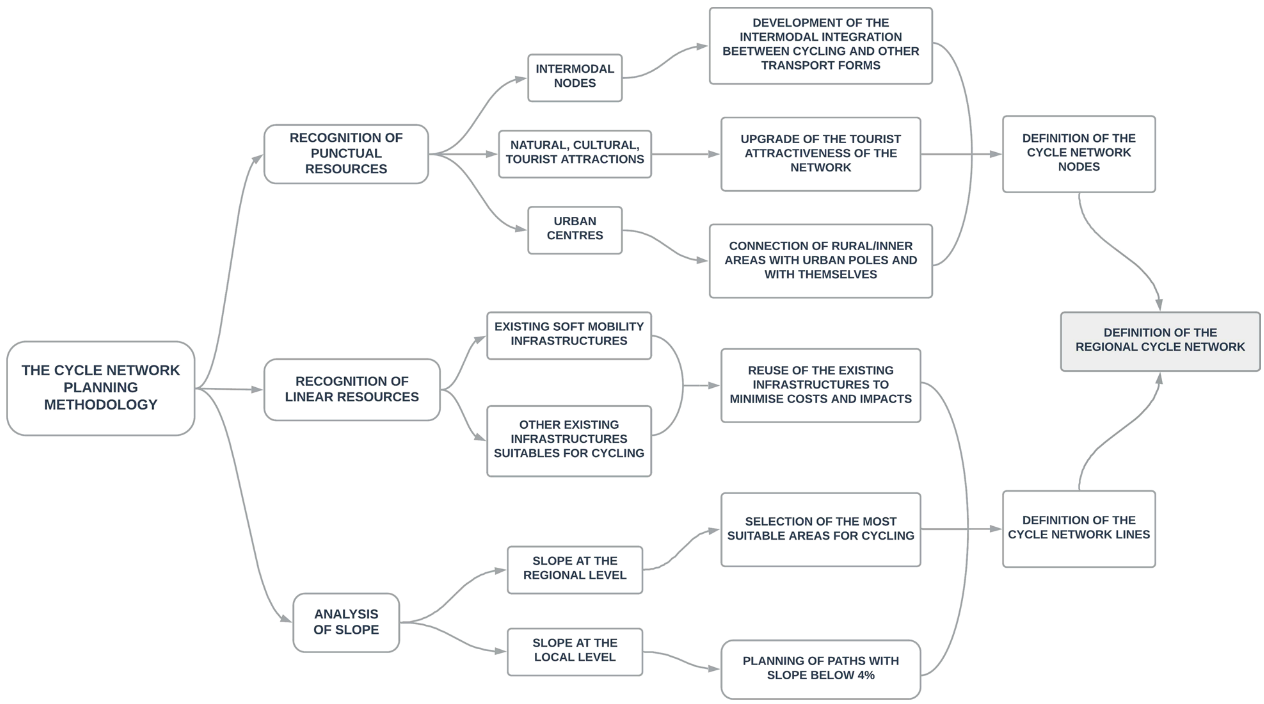

Fig. 2 Diagram flow of the regional cycle network planning methodology

infrastructural components, namely physical and social [24].

The physical infrastructure components are interventions in the environmental context so it is favourable to bicycle use. The main interventions concern the network of cycle routes on which cyclists can travel separately from motor vehicles or on shared roads at low speed, but cycling facilities, intermodal nodes, signage, and so on, are also addressed. The social infrastructure components, on the other hand, concern measures aimed at promoting the cycling system and its correct management during the operational phase.

In planning the cycle network, we used a GIS-based multi-stage process that made it possible to identify corridors at the regional level within which to subsequently design the cycle routes (Fig. 2). The strategy adopted refers to the reticular approach, recognized as a fundamental element in the field of planning to allow the territory to be made accessible in terms of the safety and comfort requirements of different categories of users [31].

The first step of the planning process involved the recognition of the existing cycle infrastructure (mainly urban and local cycle routes and networks) and the ongoing projects relating to soft mobility in the region (mountain bike routes, hiking trails, bridleways). This allowed us to identify the areas which had already developed the best active mobility infrastructure, which could then be taken as reference points for the development of cycling in the rest of the region.

A second important step in the recognition phase was the analysis of existing infrastructures in the region which were currently under- or disused but were potentially suitable for cycle use. Under this phase, three main categories of infrastructure were identified (Fig. 3):

- disused paths in the regional railway network (300 km);
- embankment paths and tracks along the canals (2800 km); and
- local and rural minor roads with low traffic levels (7300 km).

The objective was to have an overview of the infrastructure already in place which, although not dedicated cycle routes, was suitable for adaptation and inclusion in the network, so as to minimise costs and impacts, limit land consumption, and enhance existing assets [9].

The regional cycle network was conceived as a complex system of lines and nodes. While the lines represent the identified cycle routes, the nodes consist of the points

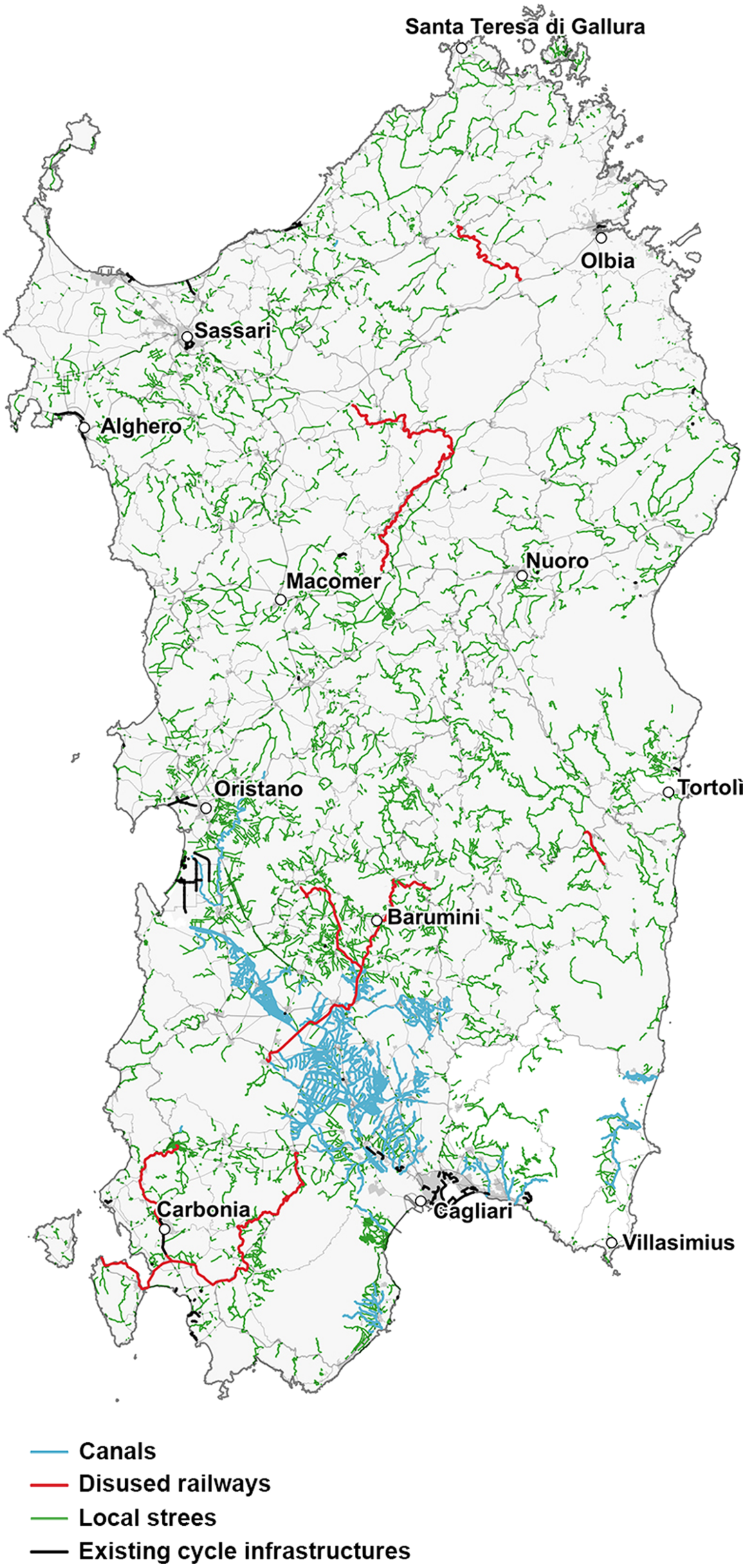

Fig. 3 Existing infrastructure suitable for cycling

of interest that the routes must connect, selected from within the following categories:

1. intermodal nodes;
2. urban centres; and
3. natural, cultural, and tourist attractions.

The first category includes nodes of access to the island from the outside (ports and airports) as well as those that allow mobility within the island (railway stations and public transport stops) (Fig. 4). It is essential to integrate the cycle network with these two types of nodes so it can be directly reached by the flows generated by the non-resident tourist population. The train stations on the historical railway lines collectively called the "Trenino Verde" constitute another important type of intermodal node. These four lines, built in the second half of the nineteenth century to connect inland areas with the coasts and ports, are currently active during the tourist season as slow tourist lines. These nodes were selected to further develop the intermodal synergies sought between cycling and other means of transport.

Analysis within the second category of nodes aimed to select urban centres whose territory was crossed, whether directly or indirectly, by the network (Fig. 5), with particular regard to:

- connecting the smaller inland urban centres to the main urban centres, in order to satisfy the demand for travel from rural to urban areas;
- connecting smaller urban centres to develop alternative forms of mobility between those which could be easily travelled between by bicycle; and
- developing cycle paths through the rural areas of the municipalities in order to encourage forms of sustainable tourism and leisure mobility.

With reference to this last point, the third category was crucial in ensuring the network was attractive to tourists and took in (Fig. 6):

- natural and environmental points of interest, such as national and regional parks and protected areas in the Nature 2000 network; and
- historical and cultural points of interest, such as a UNESCO heritage site and other archaeological sites, museums, churches, etc.

After selecting the main nodes, another fundamental step, given Sardinia's terrain, was to analyse the slope in order to compare different solutions for the same route. This analysis was performed in the GIS environment, using the digital elevation model with 10-m grid spacing provided by the Autonomous Region of Sardinia.

This last step made it possible to carry out a double-scale geomorphological analysis (Fig. 7), as further described below:

- at the regional level, it made it possible to identify the most suitable areas for cycling and those areas where cycling can be physically demanding; and
- at the local level, it permitted us to calculate the longitudinal slope of roads and paths, avoiding those with a very steep slope and planning route solutions with an average slope of less than 4%.

3 Results

The methodology outlined in the previous section allowed us to define a regional cycle network which, once completely built, will extend over 2098 km and connect 231 of the 377 municipal territories in the region. The network is divided into 46 cycle routes and six bike + train routes, which are those combined with the four lines of the historic railway (Fig. 8). This cycle network will enable 260 km of disused railway to be recovered for conversion into routes exclusively dedicated to cycling and other forms of soft mobility. Sixty km of embankment paths and tracks along the canals will be converted into segregated paths, as they are only used by motorized canal maintenance vehicles, while 580 km of local and rural minor roads will be included in the network as mixed routes where low traffic levels allow cyclists to share the path with other vehicles. Hence, the cycle network will play a decisive role in the sustainable regeneration of the territory and the reuse of its existing resources.

Accessibility from outside the region is guaranteed by the fact that the network is connected to the island's three airports and four main commercial ports, identified as island "gateway" transport nodes. Accessibility within the region is guaranteed by intermodal connections with 49 railway stations and 432 local non-urban public transport stops.

The network reaches one national park, two regional parks, over 80 sites belonging to the Natura 2000 network, as well as a UNESCO site and more than 700 other cultural and natural points of interest scattered throughout the region.

According to the OECD classification, 99% of the municipalities reached by the planned regional cycle network are classified as rural areas, corresponding to 61.2% of all rural areas and housing a population of 1,208,229 inhabitants (equal to 74% of the total). More than 75% of

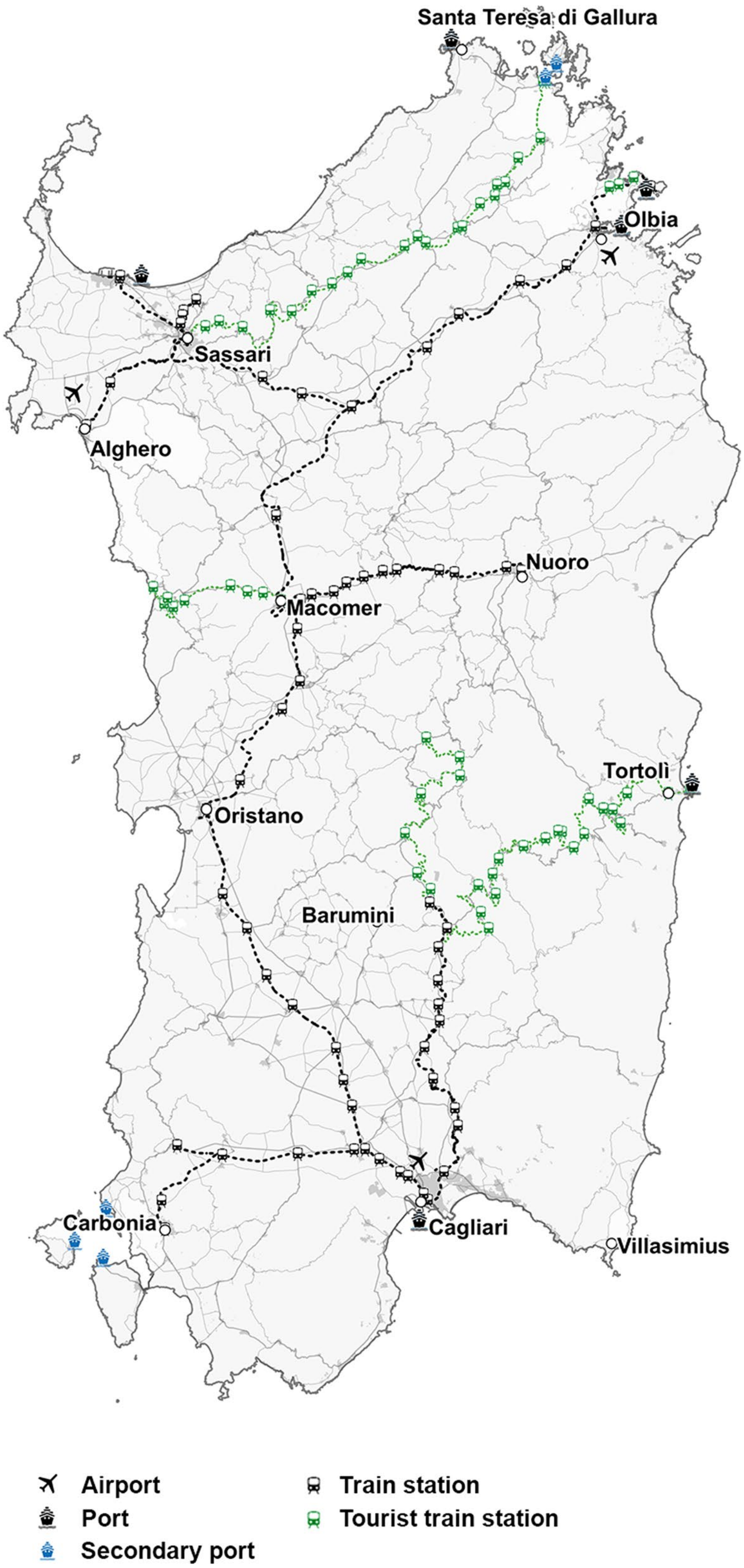

Fig. 4 Intermodal nodes

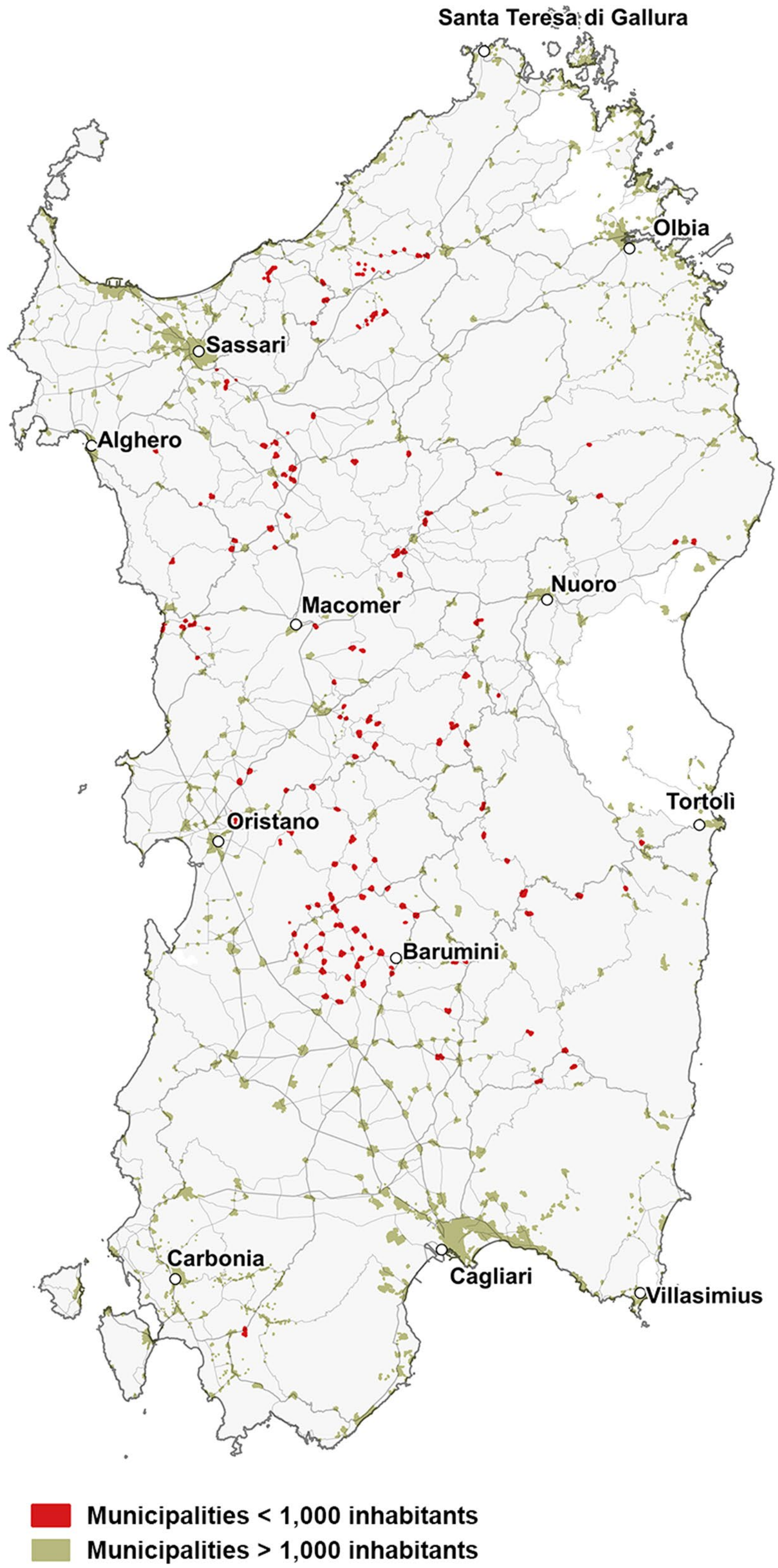

Fig. 5 Urban centres

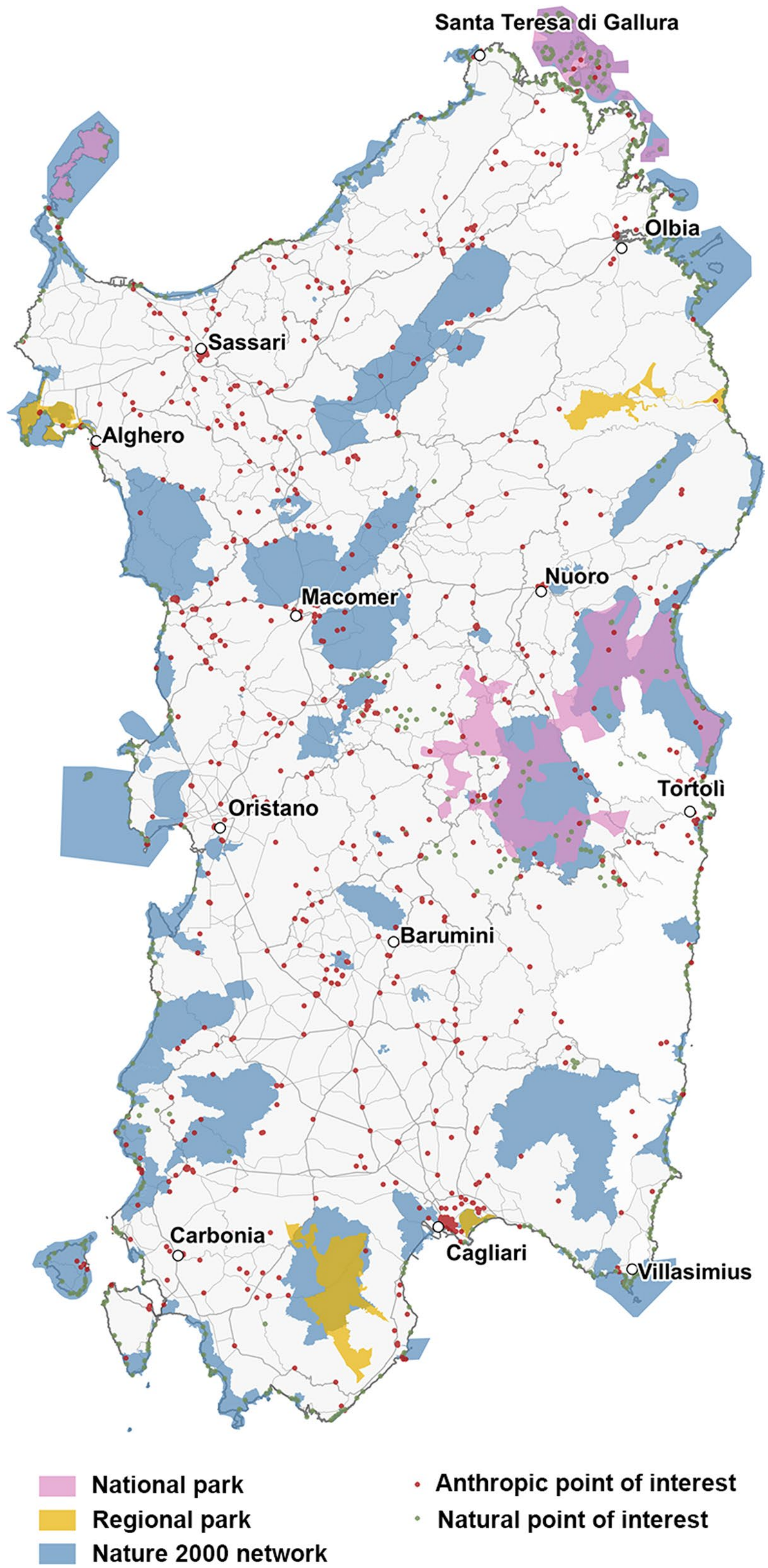

Fig. 6 Natural, cultural, and tourist attractions

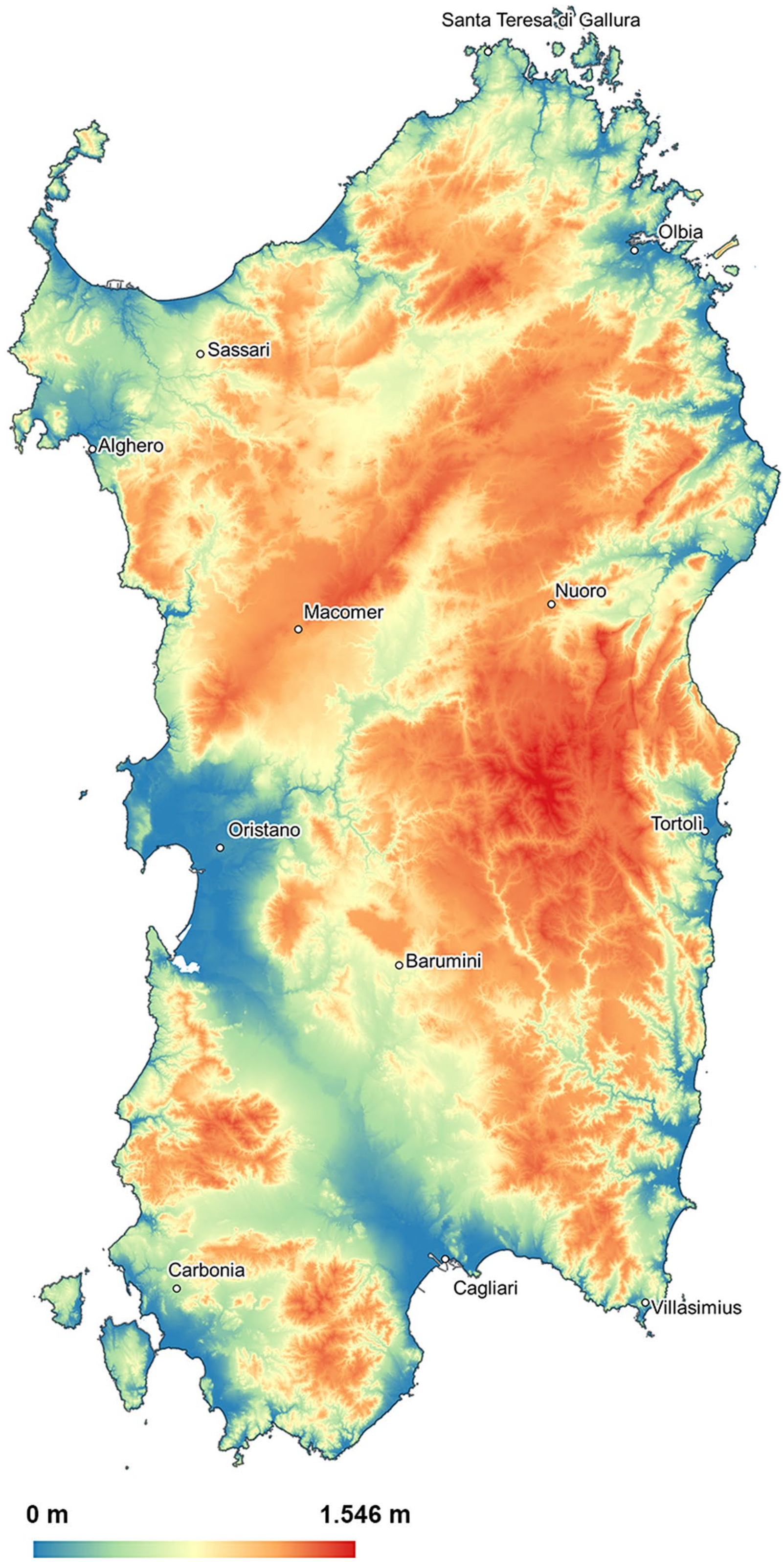

Fig. 7 Geomorphological analysis at the regional level

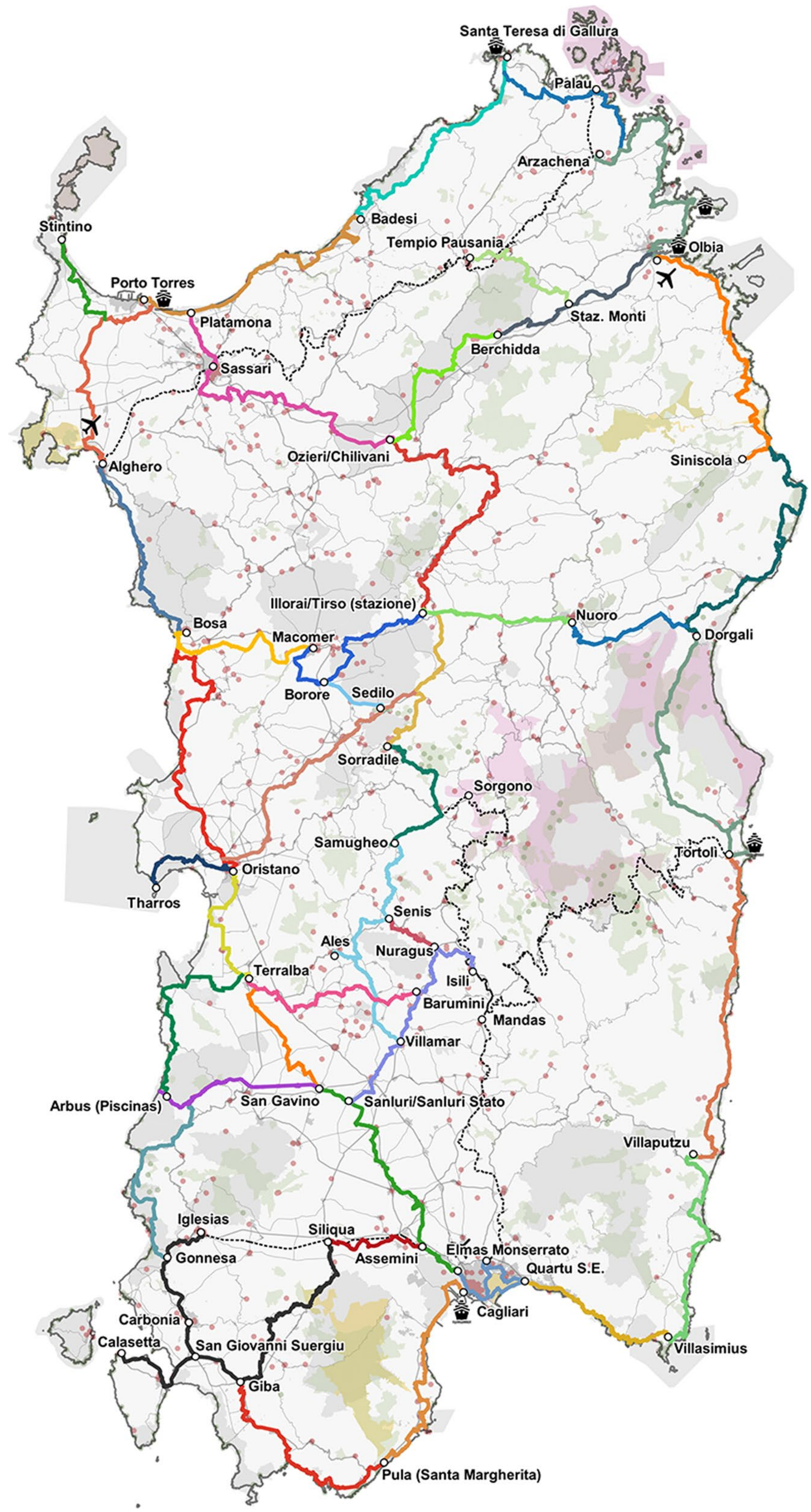

Fig. 8 The regional cycle network of Sardinia

Table 1 Municipalities in rural areas reached by the cycle network

Type of route	No. mun	Type of rural area	No	Population (2018)
Cycle route (1)	189	Rural area with intensive and specialized agriculture	9	123,971
		Intermediate rural area	39	438,779
		Rural area with development problems	140	560,207
		Total	188	1,122,957
Bike + Train (2)	42	Rural area with intensive and specialized agriculture	–	–
		Intermediate rural area	7	20,132
		Rural area with development problems	35	65,139
		Total	42	85,271
Total (1 + 2)	231		230	1,208,228

Mun. municipalities

these municipalities fall into the last class, namely "rural areas with development problems" (Table 1 and Fig. 9). Furthermore, the network directly crosses 130 urban centres, of which 99% are rural areas housing a total population of 1,020,984 inhabitants (equal to 62% of the total (Table 2).

Rural areas have been connected with the main urban poles through a hierarchically-structured cycle network which identifies long, medium, and short routes both regionally and locally. In this structure, the primary network is made up of medium and long itineraries which allow (1) the marginalization of smaller centres to be reduced by strengthening connections with the main urban centres and centres offering essential services; and (2) coastal areas, the largest and most congested urban sites, and adjacent inland areas to be connected; while short routes aim to (3) avoid the formation of a few centres of preferential attraction by creating a network that encourages inter-municipal associations so that essential services and local development strategies can be shared.

With reference to the last point, we conducted an analysis of the planned cycle network to understand its potential to connect small towns in inland and rural areas. Through the help of the geoprocessing tool in a GIS environment, we intersected the paths of the cycle network with the envelopes[1] of the urban centres crossed by them, to verify the average distance between the urban settlements.

As shown in Table 3 and Fig. 10, 57 cycling connections between urban centres are less than 10 km long, with an average distance of around 5 km. A further 20 connections are longer but still under 15 km, with an average distance of around 12 km.

Looking at Fig. 10, it is interesting to observe how most of the connections of under 10 km run through the urban centres of inland areas located in the central-southern part of the island. In fact, small towns are scattered throughout this area, close to, and easily reachable from, each other. Stretches of between 10 and 15 km are closely integrated with the shorter ones and further expand the possibilities of connecting the small rural centres of central Sardinia.

In addition, considering the tourist-recreational nature of the planned cycle routes, we analysed stretches of less than 30 km, which is assumed to be an acceptable length for a daily bike excursion open to all users. Thus, we identified a further 14 stretches with an average length of 22 km. In this case, it is interesting to note that these are mainly located near the main urban centres and coastal areas, where there is a high demand for tourism and mobility, and they offer a means to connect to inland areas.

4 Comparing the performance of cycle networks to assess transferability

To evaluate the proposed methodology to plan the Sardinian cycling network and understand its effectiveness in identifying the best cycle paths between the main nodes of rural areas, we developed further analyses of regional cycle networks planned in other Italian regions. The object of these analyses was to evaluate the performances achieved by other cycling systems in rural areas and compare them with those of the Sardinia cycle network, so as to understand if the reticular approach employed produces better results. This, in turn, would lead us to recommend it be applied in other regions.

In particular, we report our comparison with the case study of the cycle network of Piedmont, a region of northern Italy that has been developing a region-wide

[1] The envelope of the urban centres of Sardinia is contained within the dataset "Urban centres—polygons" provided by the geoportal of the Autonomous Region of Sardinia. The dataset consists of the perimeter of the urban centres extrapolated and reworked on the basis of the ISTAT census sections of the year 2001.

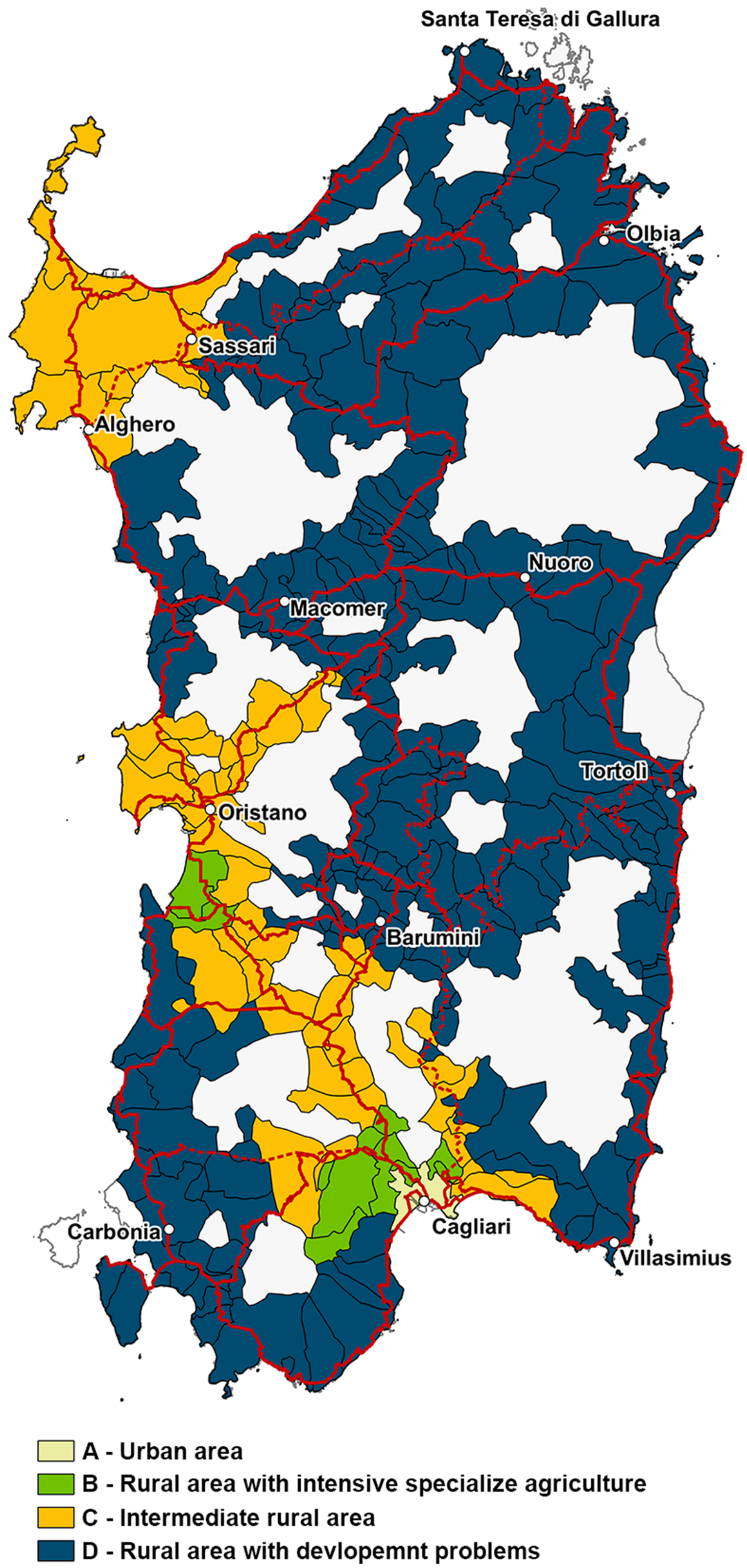

Fig. 9 Types of municipalities crossed by the cycle network according to the OECD classification

Table 2 Urban centres in rural areas crossed by the cycle network

Type of route	No. urban centres	Type of rural area	No	Population (2018)
Cycle route (1)	114	Rural area with intensive and specialized agriculture	8	113,815
		Intermediate rural area	26	312,144
		Rural area with development problems	79	398,271
		Total	113	824,230
Bike + Train (2)	17	Rural area with intensive and specialized agriculture	–	–
		Intermediate rural area	3	12,828
		Rural area with development problems	14	32,755
		Total	17	45,583
Total (1 + 2)	131		130	869,813

Table 3 Connections between urban centres provided by the cycle network in the range 0–30 km

Range	Nr. of connections	Average distance
< 10 km	57	5.43 km
10–15 km	20	12.14 km
15–30 km	14	22.04 km
Total	91	

cycle network project since 2015. The comparison with Piedmont is interesting, because the two case studies have a rather similar regional area and extension of the planned regional cycle network, as reported at the top of Table 4. Under the OECD parameter, Piedmont also has a high percentage of rural areas (99% of its municipalities) but higher population density. Moreover, as its geographical location positions it more favourably with respect to Italy and Europe, these are mostly classified in the intermediate categories (B and C). As concerns bike use, 62.8% of the population of Piedmont cycle for any purpose, a percentage higher than that of the Sardinian population (41.6%) [16].

The approach used to define the Piedmont regional cycle network was divided into three main phases [29]. The first phase concerned the definition of a methodology for selecting the cycle paths that make up the backbones of the network. In this phase, the standards and requirements that the routes must guarantee in terms of linearity, safety, coherence and attractiveness of the route were defined and the technical characteristics that the cycling infrastructures must possess were identified. The second phase concerned the recognition of the existing routes on a local scale and their overlap with those on a trans-regional and transnational scale, with the aim of giving continuity to the cycle paths beyond administrative borders. In the third phase, the main routes identified in the previous phase were examined on detailed maps and through in-site inspections to identify the necessary interventions for their implementation or adaptation and the existing problems and obstacles. The cycle network approved in 2015 extends over approximately 3400 km and consists of 13 itineraries, of which ten are cycle routes and three are bike + train routes, as they are combined with the ordinary railway. However, the cycle network was mainly planned around the recognition and systematization of existing cycle routes and then consolidated both locally and throughout the region. As a result, this approach led to the need to implement a review phase of the cycle network to collect further requests for its enlargement in areas that initially were not included; this review phase started in 2017 and ended in 2019 with the approval of a new layer of the regional cycle network [30] of which, however, no planning details were specified and therefore it was not considered in our study.

To evaluate the cycling networks of Sardinia and Piedmont, we first reconstructed, in a GIS environment, the system of lines and nodes that make up the Piedmont cycle network, starting from the data provided by the regional geoportal. Subsequently, by calculating the related indicators, we compared the performance of the two case studies by analysing the degree to which the cycle paths could connect with the different categories of nodes that shape rural areas and that an effective regional cycle network must connect:

1. municipalities and urban centres (and their population);
2. intermodal nodes (airports and railway stations); and
3. natural, cultural, and tourist attractions (parks, natural areas, and points of interest).

As shown in Table 4, as concerns category 1, the comparison between the performances of the cycling networks of Sardinia and Piedmont highlights that, in percentage terms, the methodological approach

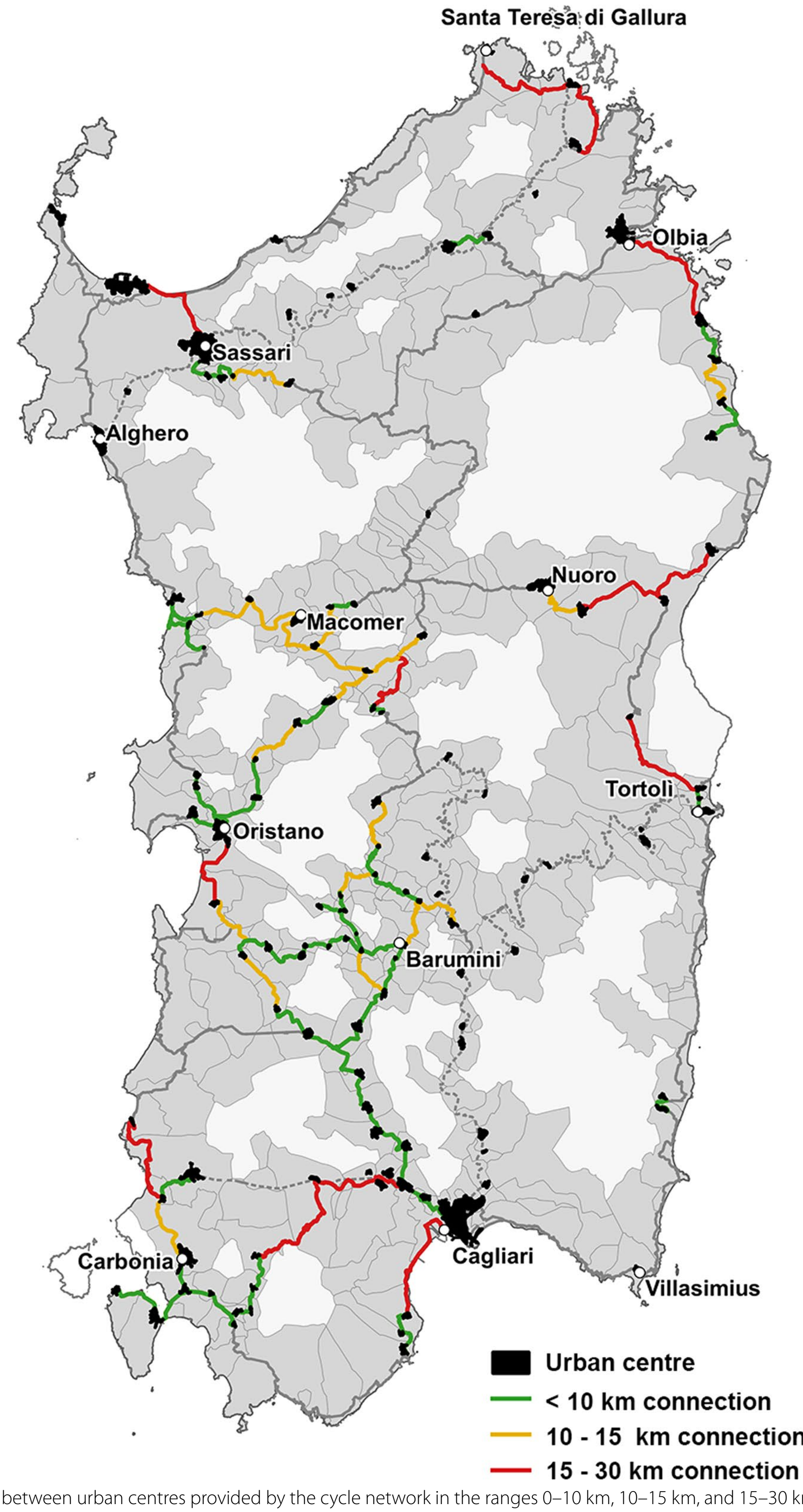

Fig. 10 Connections between urban centres provided by the cycle network in the ranges 0–10 km, 10–15 km, and 15–30 km

Table 4 Comparison between the performances of the Sardinia and Piedmont cycle networks

Regional data			Sardinia		Piedmont	
Cycle network extension			2.098 km		3.267 km	
Area			24.090 km^2		25.387 km^2	
Total population			1,64 M		4,36 M	
Population density			69/km^2		175/km^2	
% of population > 18 years that commute by bike			1.36%		2.40%	
% of population > 18 years that use a bike for any purpose			41.6%		62.8%	
OECD Rural areas municipalities/total			376/377	99,7%	1173/1181	99,3%
Regional cycle network data			**Sardinia cycle network**		**Piedmont cycle network**	
1	Mun	Mun. reached	231/377	61.3%	508/1181	43.0%
		Mun. in rural areas reached	230/376	61.2%	500/1173	42.6%
		Pop. of rural areas involved	1.208.228	74.1%	2.318.309 (53.3%)	53.3%
	UC	UC reached	131/377	34.7%	326/1181	27.6%
		UC. in rural areas reached	130/376	34.6%	318/1173	27.1%
		Rural areas' pop. involved	869.813	53.3%	1,594,015	36.6%
2	IN	Airports	3/3	100%	0/2	0%
		Railway stations	49/67	73.1%	112/277	40.4%
3	NCTA	Parks	3/7	42.9%	9/27	33.3%
		Natura 2000	80/125	64.0%	54/180	30.0%
		POI (1 km)	745/1624	45.9%	520/2017	25.8%

M million, *Mun.* municipalities, *Pop.* population, *UC* urban centres, *IN* intermodal nodes, *NCTA* natural, cultural, and tourist attractions, *POI* point of interest

adopted in planning the Sardinian cycle network allows a greater number of municipal territories to be reached and connected; moreover, a greater number of rural areas and a greater percentage of the regional population were involved, despite Sardinia's lower population density. In addition, the number of urban centres directly crossed by the cycle network is higher, both in absolute terms and in terms of urban centres belonging to rural areas, despite there being far fewer centres. Even within this sub-category, the cycling network of Sardinia is able to reach more people than that of Piedmont.

Moving on to the second category, as regards the intermodal nodes, the Piedmont network does not consider the need to ensure direct connections between the cycle network and the airport system. This indicator, which was considered essential in Sardinia, may perhaps be secondary in a non-island region which is easily accessible by land transport at both national and European level. However, at the same time, the Piedmont cycle network has fewer direct connections with railway stations, which is important to allow the cycle network to be reachable from areas which are not included in the network as well as by public transport.

With reference to the third category, which defines the attractiveness of the network from a tourist and recreational point of view, the analysis shows that the approach adopted in Sardinia allows for a greater number of natural, environmental, and cultural resources to be incorporated into the cycle network.

To sum up, the comparison shows that the use of a reticular approach in planning rural cycling routes at a regional level enables better results in terms of connecting the three essential elements of a rural territory, namely (1) settlement, (2) mobility, and (3) land resources.

Furthermore, the comparison highlights how the approach adopted in a starter cycling region such as Sardinia allows strategic planning to be exercised which can guide the development of an effective cycling network in a rural area. In contrast, even in a region where cycling is on the rise, such as Piedmont, where a higher percentage of people uses bikes and some cycle routes are already in existence, an approach based mainly on incorporating existing paths produces a planning method which is based on local and short-term interventions but lacks a strategic, region-wide framework.

5 Discussion and conclusions

The phenomena of marginalization, depopulation, and the abandonment of villages in rural and inland areas due to the growing expansion of the urban population affect much of Sardinia. The regional cycle network plan illustrated in this study aims to provide an answer to these problems by reinterpreting the role and value of these villages. The overall picture presented by this document tries to identify the strategies put in place to create a regional network which can increase access to rural areas by promoting sustainable forms of mobility and tourism. By adopting the methodology described here, we were able to plan a physical infrastructure by applying criteria aimed at connecting a significant number of urban centres, places of historical, archaeological, and cultural interest, areas of environmental interest, island gateways, and a sufficient number of intermodal nodes so as to improve the accessibility of the innermost and most marginal areas of the island.

From the comparison made with a cycle network planned in another Italian region, Piedmont, where a different methodology was used, it appears that the proposed reticular approach to planning a regional cycle network guarantees that rural areas will be better connected and there will be greater access to their resources. In fact, the comparison with Piedmont highlights the importance of using this methodology from the strategic planning phase of a regional cycle network in order to achieve better planning results, rather than an a posteriori approach that models the network on the basis of existing cycle paths and does not apply a single, region-wide strategy.

The development of a network around a linear infrastructure, such as cycle routes, has the potential to stimulate the clustering of small interconnected municipalities, developing a new role for individual settlements. Whereas a reasonable distance for commuters by bicycle is normally considered to be under 10 km [7, 33], the potential to connect small towns generated by the cycle network appears interesting. In fact, it transpired that 50% of the connections within the cycle network are of a length that can be travelled by a normal commuter who uses a bicycle for their daily journeys. Furthermore, since these are connections that pass through extra-urban territory, these distances can be travelled with greater safety and speed than is possible when moving through a busy urban context full of obstacles. This specific configuration of the network can also generate a spill-over effect [26]. Some people may start cycling for leisure, and then, once used to this means of transport and helped by the small distances, they may be persuaded to cycle for utilitarian purposes (commuting, errands, shopping). Considering that in the near future it will be increasingly necessary to find better ways for essential services to be shared among small municipalities in order to prevent them being abandoned because services are not available to inhabitants, the cycling network can offer a valid sustainable mobility solution to meet daily needs.

From a tourist point of view, the plan lays the foundations for an active mobility system which can promote an innovative and sustainable way to discover the region, with particular attention paid to its inland areas. The tourist experience facilitated by the plan is not an alternative to the existing one but, rather, intends to merge with it in a sustainable way, by developing year-round activities and distributing tourist flows island-wide. This would allow the current tourist season to be extended in both time and space. Implementation of the project can have a direct positive impact through direct tourist expenditure, and an indirect one by boosting the local economy through the creation of facilities for cyclists such as bike service shops, spare parts, and hospitality.

Finally, we would like to state that the improvement of physical accessibility, which, in turn, would generate positive impacts at all economic and social levels, depends on several conditions. A key role will be played by governance, both for the creation of the physical infrastructure and the subsequent management of the entire system. A management body at the regional level will be essential to ensure the coordination of the various actors involved and serve as the necessary link between local and central levels. Giving single municipalities free rein, without coordination of this type, would lead to a fragmented and scarcely connected cycling network, which would not connect rural areas in a sustainable way.

Abbreviation
OECD: Organisation for Economic Co-operation and Development.

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Authors' contributions
B.S.: conceptualization, methodology, formal analysis, writing—original draft. V.Z.: investigation, data curation, formal analysis, writing—original draft. I.M.: funding acquisition, project administration, writing—original draft. F.P.: formal analysis, writing—original draft. All authors read and approved the final manuscript.

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