New indicators for sustainable tourism and transport networks resilience: the case study of Bari (Italy)

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On cover: Basilica di San Nicola (Bari)
Ph: Fulvio Morgese

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Doctorate in Risk And Environmental, Territorial And Building Development

04
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Coordinator: Prof. Vito Iacobellis

XXXVII CYCLE
Curriculum: ICAR/05-Transportation

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Tutor: Prof. Michele Ottomanelli, Prof. Leonardo Caggiani
Co-tutor: Prof. Mario Binetti
DICATECh Department of Civil, Environmental, Building Engineering and Chemistry
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LIBERATORIA PER L'ARCHIVIAZIONE DELLA TESI DI DOTTORATO

Al Magnifico Rettore
del Politecnico di Bari

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residente a **POLIGNANO A MARE** in via **CONTRADA CASE SPARSE NC** e-mail **fulvio.morgese@poliba.it**

iscritto al 3° anno di Corso di Dottorato di Ricerca in **RICHIO E SVILLUPPO AMBIENTALE, TERRITORIALE ED EDILIZIO** ciclo **37**

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New indicators for sustainable tourism and transport networks resilience: the case study of Bari (Italy)

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La borsa di dottorato è stata co-finanziata dall'Istituto Nazionale Previdenza Sociale (INPS) con risorse a valere sull'Avviso alle Università - Ricerca e selezione di Dottorati di ricerca

***EXTENDED ABSTRACT** (eng)*

The social, economic and cultural perception of cities is strongly influenced by the tourism sector.

Micro-mobility, particularly cycling, plays a significant role in providing sustainable and efficient transport between accommodation and tourist attractions.

The growing popularity of cycle tourism, driven by trends in experiential, slow and active tourism, highlights the need for awareness of public authorities and administrations in decision-making through quantitative and qualitative methods.

Assessing the level of cycling in cities is essential to promote sustainable tourism, and factors such as safe infrastructure or public transport services including bike sharing systems are crucial.

In this study, a survey of all municipalities in Puglia is initially presented, which provides a snapshot of the current state of services and infrastructure in the region and can guide stakeholders to expand cycling services.

This thesis work involved the construction of four new cycling indicators. The first two concern tourist accessibility both in the urban area and at the broader level of the metropolitan area of Bari (Italy), which include multimodal public transport-cycling systems, capable of identifying areas requiring infrastructure improvement.

Sustainable tourism is becoming increasingly important as shared micro-mobility systems allow users to cover short to medium distances independently and sustainably. Their use can be strategic during major events, because of their availability and capacity to avoid traffic.

The theme of sustainable tourism is further supported in this thesis work by the assessment of the resilience of urban road networks during major events, with a focus on the integration of micro-mobility.

A model is presented that on the one hand enables the promotion of cycling mobility and on the other hand reduces the inconvenience caused by the closure of urban roads for large events such as sporting events or festivals.

Finally, after delving into the topic of the resilience of transport networks, another last one, the fourth in this work of thesis, is presented. It is an indicator that assesses the sustainability of transport modes for tourism through Data Envelopment Analysis, providing municipalities with a tool to improve urban infrastructures with a further in-depth case study in the city of Bari.

Keywords

Resilience, Accessibility, Sustainable Tourism, Cycling Tourism, Bike Friendly Cities, Bike Friendly Services, Multimodal Trip, Urban Road Network, Data Envelopment Analysis.

EXTENDED ABSTRACT (ita)

L'industria turistica è un fattore critico nel determinare la percezione culturale, economica e sociale delle città.

La micromobilità, in particolare la bicicletta, svolge un ruolo significativo nel fornire un trasporto sostenibile ed efficiente tra le strutture ricettive e le attrazioni turistiche.

La crescente popolarità del cicloturismo, guidata dalle tendenze del turismo esperienziale, lento e attivo, evidenzia la necessità di consapevolezza degli enti pubblici e delle amministrazioni nel processo decisionale attraverso metodi quantitativi e qualitativi.

Valutare il livello di ciclabilità delle città è essenziale per promuovere un turismo sostenibile, e fattori come la sicurezza delle infrastrutture o i servizi del trasporto pubblico compresi i sistemi di bike sharing sono fondamentali.

In questo studio viene inizialmente presentata un'indagine condotta su tutti i comuni pugliesi che fotografa lo stato attuale dei servizi e delle infrastrutture presenti nella regione e che può indirizzare gli stakeholder ad espandere i servizi ciclistici.

Questo lavoro di tesi ha riguardato la costruzione di quattro nuovi indicatori di ciclabilità. I primi due riguardano l'accessibilità turistica sia nell'ambito urbano che al livello più esteso dell'area metropolitana di Bari (Italia), che includono sistemi multimodali di trasporto pubblico-bici, in grado di identificare le aree che richiedono il miglioramento delle infrastrutture.

Il turismo sostenibile sta diventando sempre più importante, poiché i sistemi di micromobilità condivisa consentono agli utenti di coprire distanze medio-brevi in modo indipendente e sostenibile. Il loro utilizzo può essere strategico durante i grandi eventi, grazie alla loro disponibilità e capacità di evitare il traffico.

Il tema turismo sostenibile è ulteriormente supportato, in questo lavoro di tesi, dalla valutazione della resilienza delle reti stradali urbane durante i grandi eventi, con particolare attenzione all'integrazione della micromobilità.

Viene presentato un modello che consente da un lato di favorire la mobilità ciclistica e dall'altro di ridurre i disagi dovuti alla chiusura delle strade urbane per lo svolgimento di grandi eventi come manifestazioni sportive o feste patronali.

Infine, dopo aver approfondito il tema della resilienza delle reti di trasporto, viene presentato un altro ultimo, il quarto di questo elaborato. È un indicatore che valuta la sostenibilità delle modalità di trasporto per il turismo attraverso la Data Envelopment Analysis, fornendo ai comuni uno strumento per migliorare le infrastrutture urbane con un ulteriore caso studio approfondito nella città di Bari.

keywords

Resilience, Accessibility, Sustainable Tourism, Cycling Tourism, Bike Friendly Cities, Bike Friendly Services, Multimodal Trip, Urban Road Network, Data Envelopment Analysis.

INDEX

INTRODUCTION

The research conducted is focused on the resilience of the urban transport network and makes it possible to analyse urban planning, control the transformation undergone by a city, and rethink public spaces, improving the organisation of the ecosystem relations that populate and infrastructurise these spaces. To do this, the research activity started from an analysis of tourism in Apulia, in particular in the city of Bari, which led to the construction of four indicators, the first two of which calculate tourist accessibility and were the basis for proposing two other main resilience indicators.

Building, civil and environmental engineering, declined on the theme of sustainability, finds a multidisciplinary field of strong technical-scientific interest on the subject of resilience, with explicit reference to the reaction of cities to events of great impact that provoke long-term phenomena such as climate change.

In this context, the need to introduce characteristics of effective sustainability in the organisation and physical transformations of urban spaces is evident. In the course of the research, the author deemed it necessary to investigate the sustainable tourism sector and some sustainable modes of transport through the use of bicycles and public transport.

The general objective is therefore framed in the increase of a city's degree of resilience, which is measured in its capacity to evolve, resolving and metabolising such pressures and disruptions that encompass and affect problems of mobility and congestion, fluctuations and crises in the real estate market, and conflicts of an economic and social nature.

The methodology used was oriented to develop analysis and investigation paths oriented to a better spatial, planning and infrastructural organisation able to minimise socio-environmental risks, with a view to sustainable development with reference to specific contexts related to events of anthropic origin, such as overtourism. The external collaboration with ASSET (Agenzia per lo Sviluppo Eco Sostenibile del Territorio della Regione Puglia - Agency for the Eco-Sustainable

Development of the Territory of the Apulia Region) allowed the doctoral student to start a collaboration on several closely related issues concerning urban and inter-urban mobility through the transversal interaction with the different functional areas present in the organisation of the public body, including 'Network Infrastructure and Mobility, Landscape and Environment'.

The research phase carried out abroad, at the Universidad de Cantabria, with the SUM LAB Movilidad Sostenible and Ingeniería Ferroviaria Research Group, allowed for an in-depth study of sustainable mobility issues with particular regard to the definition of resilient integrated models and scenarios between the risk of critical events, land use and mobility.

The specific objective was to contribute to the realisation of effective decision support systems in the production of plans, projects and policies for the prediction and management of critical events and the monitoring and adaptation to the impacts of long-term phenomena, introducing in this context the evaluation of the resilience of the urban system, i.e. the long-term beneficial effect generated by an improved capacity of immediate reaction of the transport system to critical events of various kinds.

The research results obtained may have direct repercussions on regional legislation on territorial government, on programming and planning tools, as well as on the supervision and refinement of public funding with a view to environmental sustainability. In particular, the ultimate goal is to improve the resilience of an urban transport network by orienting it towards increasingly sustainable mobility.

The organisation of the chapters of this work is described below. Before being able to present the different indicators proposed, it is necessary to study and deepen the state of the art (c.1) that is proposed and explained in the first chapter of this thesis.

A good cycling experience is certainly characterised not only by the route travelled but also by the services on that route. In the second chapter (c.2), therefore, an in-depth analysis is made of the bike-friendly services present in the Apulia Region in particular.

Subsequently, in the third chapter (c.3), we will begin to delve vertically into the various themes addressed, starting with the concept of tourist accessibility, which influences the experience of any tourist who decides to travel by one of the most sustainable modes that exist in urban areas, namely by bicycle. The first indicator of this thesis of tourist accessibility by bicycle is thus presented, with the first case study applied to the city of Bari, one of the most successful European destinations in recent years.

But the sustainable tourist can be defined in this way if he or she also integrates the use of public transport for the reasons of his or her movement; therefore, in the third chapter the theme of multimodality is addressed through the construction of another indicator, the second of this thesis. Also, in this chapter (c.4) we will see an application on Bari, considering the entire territory within the boundaries of the metropolitan city.

The fifth chapter (c.5) is dedicated to the relationship between urban resilience and sustainable tourism. In this chapter we find two new indicators with two case studies, both applied to the city of Bari, which explain the meaning of efficiency and resilience. The last chapter is dedicated to the final discussion that leaves room for the conclusions of the entire thesis work.

“The tourism of the future? It starts with the locals, with their quality of life, their ability to be happy and their respect for the land they live in. Then the tourists will find the way!”
Carlo Petrini, *founder of SlowFood*

1. Literature Review

1.1. Sustainable tourism services

Cycling is gradually gaining popularity over motorized transportation, both for urban trips and tourism excursions. This is due to the facts that this transport mode offers several benefits that align well with the principles of resilience: it has health benefits, due to the physical exercise needed to ride the vehicles; it has a small climate footprint, both in terms of environmental and noise pollution and reduced energy consumption; it offers economic boosts to local retailers and promotes socialization among people on the street. Transport plays a key role in people's daily lives as it is often linked to the amount of economic and social opportunities people can access, how far they can reach essential services such as health or food, and how fully they can participate in society (Allen and Farber, 2019; Litman, 2002).

The resilience of bike mode has been proved in several research. Clemente (2020) proved the contribution made by bicycle networks to improve stormwater collection and management in the case of Boston, San Francisco, Zwolle and Copenhagen. (Philips et al., 2013 highlighted the role of active mobility in increasing the resilience of transport systems to disruptions, analyzing in detail the accessibility to work in case of fuel shocks. (Cheng et al., 2021) used an autoregressive negative binomial time series model to investigate the effects of public transit closures on bike sharing demand in Washington, D.C. during 2015–2017; they found that bike sharing can act as a supplementary mode in the case of complete transit closure. The European Cyclist Federation, an umbrella organization for European cycling advocacy groups, has estimated that the combined market value of cycling-related goods and benefits across the continent amounts to EUR 150 billion per year. Of this, EUR 73 billion is attributed to the prevention of premature death, chronic cardiovascular disease, and diabetes, resulting in reduced public health spending (Steenberghen et al., 2017). For this reason, one of the primary challenges in urban transport planning is to restrict the usage of private cars while encouraging the adoption of sustainable modes of transportation (Inturri et al., 2019). In commuting to work, the bicycle also plays a key role as (Wild and Woodward, 2019) state in their evidence that cyclists are the happiest commuters. The discipline of physical activity highlights the fundamental importance of pleasure in motivating individuals to participate and maintain regular physical activity. Consequently, the design and promotion of cycling should go beyond a simple focus on safety and investigate how cycling infrastructure and services for two-wheelers enhance the physical, social, and psychological pleasures of cycling (Bullock et al., 2017). As a "flagship" of green transportation with transit attributes, bike-sharing has become particularly popular since the mid-2000s (Zhao et al., 2015). As Nilsson (2019) shows, the enjoyment of cycling also depends on crime, as measured by the number of bicycle thefts.

Overall, one can state that the use of 2, 3 or 4-wheel vehicles with a chain and pedals democratizes people's existence by improving their quality of life.

In this realm, cycling tourism is a relatively recent phenomenon in which the bicycle is the preferred mode of transport for tourism trips. It is linked to the opportunity to travel at lower speeds while enjoying the landscape and performing physical exercise. The user base for this type of activity is very wide and the phenomenon lends itself to different interpretations: sporting, vacationing, natural or simply an alternative way to travel accessible to even for the most vulnerable groups. Some studies show that the reasons why cyclists are driven to organize their bicycle vacations, or simple excursions, can be attributed to the pleasure of two wheels as a form of relaxation and sport, to be in contact with nature and the opportunity to explore places and admire landscapes (Bi et al., 2023; Useche et al., 2019), keeping a good flexibility and autonomy in the choice of itineraries. In some cases, reaching some places by bicycle may not be possible, so for proper planning it is essential to identify the adequacy of a city's infrastructure and related services for this type of travel (F. Morgese et al., 2024). Lamont, 2009, affirms that scholars are increasingly focusing on the connection between cycling and tourism, noting that cycling is undergoing a resurgence as a recreational, leisure, and sporting pursuit.

Securing the success of cycling tourism initiatives hinges on the active involvement of the public and citizens. Traditional decision-making methods may overlook the viewpoints and preferences of stakeholders, underscoring the need for participatory procedures in assessment. Moreover, a well-organized cycling tourism initiative can encourage individuals to choose cycling over other modes of transportation, thereby reducing traffic congestion, air pollution, and carbon emissions. Additionally, this exposure to cycling can educate and motivate people to incorporate cycling into their daily lives, further promoting sustainable transport habits.

With this principle in mind, this study seeks to develop a framework for assessing the rollout of cycling tourism services, particularly focusing on bike-sharing programs for the case study of the Apulian region (Italy). More in detail the study presents the results of a questionnaire, explained in chapter 2 and developed by a consortium of Apulian territorial entities including the Polytechnic University of Bari aimed at engaging city administrators, pivotal figures in the planning and execution of cycling infrastructure and services, to gather their valuable insights.

1.2. Cycling Accessibility and Multimodality trips

Tourism is a crucial factor when considering cities from a cultural, economic, and social perspective (Mazzulla et al., 2021). At the same time, if managed incorrectly, it may negatively affect the lives of residents and generate several issues. Logistics and transportation are closely related to the quality and development of tourism. In particular, the growth of micromobility and shared vehicle systems allows the establishment of more sustainable tourism.

Bikes are one of the most widely used types of transport within cities (Cirianni et al., 2018). These could be private property, provided by private entities, or rented in a sharing mode. In order to improve tourism, it may be useful to evaluate the "bike-friendliness" of cities. There are a number of parameters to take into consideration: weather conditions (for example, number of hours of sunshine, percentage of rainfall, and temperature ranges), proportion of people using bikes in everyday life, crime assessed on the number of bike thefts, and safety measured by the number of accidents, including fatalities (Magliulo et al., 2022)Nilsson, 2019). At the same time, infrastructures play an important role in the development of city tourism.

There are numerous cities that boast separate bicycle infrastructures with no road system intersections. Having lanes dedicated to bicycles improves perceived safety and increases the use of this sustainable mode of transport. In the study of Verhoeven et al. (Verhoeven et al., 2017), they used questionnaires to show that adolescents prefer to cycle if there is a division between cycle paths and other types of traffic. Having lanes dedicated to bicycles improves perceived safety and increases the use of this sustainable mode of transportation. Moreover, the location of sharing system fleets plays a fundamental role in system usage because if these are located within the vicinity of tourist attractions and facilities such as hotels, bed and breakfasts (B&Bs), and other accommodations for tourists, it makes these transport systems more attractive and of greater use when visiting the city.

The concept of *bikeability* refers to the degree to which an urban area is suitable and supportive for cycling, considering factors that influence the safety, convenience, and overall appeal of cycling for both everyday use and tourism. In the literature, various researchers have developed indicators to assess how bike-friendly cities are, with most studies focusing on functional and commuter cycling rather than tourism-specific cycling needs. When it comes to bikeability indicators, one notable example is the work of Krenn et al., 2015 developed a bikeability index for a mid-sized European city based on Geographic Information Systems (GIS) data to examine the predictive index validity and to determine the bicycle-friendliness of the city with a bikeability map. Ferwati et al., 2017 defined an urban index model, named Path Cyclability Assessment Index (PACEX), which evaluates and analyzes the cyclability of path segments, taking into consideration residents' decisions for cyclable route selection. It is based on a decision-tree-making method with the aim of analyzing quantifiable qualitative data. Hamidi et al., 2019 proposed an indicator based on accessibility measures and the Theil index of inequality with the aim of analyzing the inequalities in bike access for the main transport hubs of a city. This index takes into consideration the role of private and public bikes related to access to existing public transport systems. Kamel et al., 2020 developed a bike composite index consisting of two indices, which represent bike attractiveness and bike safety, using bike kilometers travelled and cyclist-vehicle crash data from 134 traffic analysis zones in the city of Vancouver, Canada. To this end, they took into consideration parameters such as bike network density, centrality, weighted slopes, and recreational density. Arellana et al., 2020 proposed an urban bikeability index to evaluate and prioritize bicycle infrastructure investments and improve cyclist accessibility. Codina et al., 2022 created a bikeability index with the aim of mapping the bikeability potential of a city under consideration, using objective GIS data and ten spatial indicators. This index can predict the frequency of daily bike usage considering parameters such as traffic, collisions involving bicycles, volume of cyclists, infrastructures, cycle paths and lanes, intersections, parking spaces, distance to biking stations, distance to bike racks, topography, and percentage rise.

With regard to accessibility tourism indicators, Natalia et al., 2019 defined a tourism accessibility measure focusing on people with disabilities. This index is based on data collected cross-country and cross-continent for a period of 25 years, based on principal factor component analysis. Parameters taken into consideration were: sociodemographic data, legal frameworks, political and policy actions, and access conditions for tourist attractions. Phumsathan et al., 2022 developed 32 indicators for assessing the potential for tourism development. These were based on five components: attraction, accessibility, amenity, accommodation, and activity. The indicators were used to calculate an expression termed Tourism Resource Potential. Zhang et al., 2021 developed a conceptual model with the aim of investigating the ontological value of tourism resources in their study. Six indicators were considered, of which one focused on accessibility. This can be defined as the average distance of the shortest paths from one vertex to all other vertices. Moosavi Heris et al., 2022 determined optimal travel routes considering accessibility using a team-orienteering problem with time windows to design a multi-objective model with the aim of determining optimal tourist routes. They took into consideration points of interest and proposed several indicators to calculate accessibility. Carra et al., 2023 used an integrated method with the aim of analyzing itineraries for tourism experiences within municipal councils. They considered factors such as average slope, estimated cost of realization, length, municipality crossed, points of interest, areas with dedicated lanes, train stations, priority bus stops, and unpaved surfaces.

To the best of our knowledge, in the literature, there are no indicators related to tourism that take into consideration bikes and shared systems. For this reason, we propose a first cycling indicator for city tourism accessibility based on factors presented in the literature and other cycling factors, i.e., the presence of bike-sharing systems. The aim is to define the level of bike-friendliness related to a specific city zone through numerical values which we will elaborate on in the chapter 3.

Sharing systems can be a solution for short and medium distances. However, in some cases, the tourist starting point can be far from Points of Interest (POIs) and multimodal bike-public transport may be the best solution for sustainable trips. Multimodality has been explored in a number of studies. For example, Chen and Cheng, 2016 focused on an integrated bike-rail transport service and analyzed cyclist preferences regarding this service, using an on-site choice experiment survey and mixed logit models. Results showed that cycle tourists are interested in integrated bike-rail transport services, with attention to price, type of storage, bike storage location, and service frequency. Qiu and Chang, 2021 measured the interplay between Lime dockless bike-share and bus services in Itaca, using data from records of bus stops and Lime bike-share trips where a user rides a Lime vehicle to board a bus. They found out that Lime provided useful first and last- mile transfers to bus services for commuters.

In literature, several authors have proposed indicators with the aim of exploring how bike-friendly cities are, although few of them focus on tourism.

As regards "bikeability" indicators, Krenn et al., 2015 developed a bikeability index for a mid-sized European city based on Geographic Information Systems (GIS) data to examine the predictive index validity and to determine the bicycle-friendliness of the city with a bikeability map. (Hamidi et al., 2019) proposed an indicator based on accessibility measures and the Theil Index of inequality with the aim of analyzing the inequalities in bike access for the main transport hubs of a city. This index takes into consideration the role of private and public bikes related to access to existing public transport systems.

Indicators taken into consideration in the above-mentioned studies do not consider multimodality with bicycles. Some studies analyzed multimodality from different perspectives.

For example, Scheiner et al., 2016 used the mobility biography approach to study changes in multimodality over time at an individual level. They analyzed four continuous indicators of mode use in a seven-day period. They considered variables such as socio-demographic state variables, spatial/accessibility state variables, socio-demographic change and spatial/accessibility change variables. They considered car driver, car passenger, public transport, bicycle and walking as a mode shares.

Prencipe et al., 2022 proposed a station location model for bike- sharing with equity aspects with the aim of minimizing inequalities in bicycle-public transport mobility within population groups, maintaining both specified levels of accessibility and coverage. They proposed accessibility and inequality indices and took into consideration parameters such as minimum travel time between origin and destination zone, considering the shortest path and the speed of the fastest transport mode among those considered, and the minimum travel time associated with all possible combinations of transport modes between origin zone and destination zone.

Capodici et al., 2021 carried out an analysis of cycling and rail transport services to evaluate potential mobility demand related to these services and the possibility of multimodality between bicycle and rail transport, using software GIS.

They took into consideration variables such as travel time spent from origin to destination, cycle infrastructures, age of respondents for motorcycle and car alternatives, and the gender of respondents for the bicycle and car alternatives, respectively.

Lemonde et al., 2021 proposed a methodology to analyze spatiotemporal indices of multimodality against available situational contexts. The aim was to find vulnerabilities in the public transport network. They took into consideration the intensity of use of the first transport mode (including bikes), the total number of modes, weather factors, and public events.

Zhou et al., 2021 investigated the multimodal discrete network design problem with the aim of simultaneously optimizing the car, bus and train transit networks with inter modal transit such as walking and bike-sharing, using proposed model and developed algorithms. They took into consideration travel time, cost, comfort loss, risk reserve time, network operation cost, and construction cost.

Földes and Přibyl, 2023 conducted a spatial analysis on origin-destination data of bike- sharing use, which starts or ends at a major public transport stop. The aim was to understand if bike-sharing and public transport are competitive or complementary modes. They took into consideration parameters such as weather conditions, bike rentals, distance between bike-sharing stations, and bicycle infrastructure locations.

To the best of our knowledge, in literature, there are no indicators related to tourism that take into consideration multimodality trips with bikes and public transport. For this reason, we propose a first multimodal bike and metropolitan area public transport indicator for sustainable tourism accessibility evaluation based on some factors presented in literature and other cycling factors such as the presence of bike-sharing systems. We will see this specifically in chapter 4

1.3. Major events and tourism

Many tourism destinations focus on the use of micro-mobility to solve urban problems caused by increased private car use. In the study of Zarif et al., 2019, micro-mobility systems were defined as “a tantalizing solution to address the first mile/last mile problem”. Indeed, sustainable tourism is becoming increasingly important as shared micro-mobility systems allow users to cover short to medium distances independently and sustainably. Their use may be strategic during major events, as they avoid traffic congestion and pollution that would be generated by cars. However, it is necessary to evaluate the resilience of urban road transport networks at these major events, especially concerning cycling tourism.

The concept of resilience was first introduced by Holling, 1973 in a study of ecological systems. Resilience was defined as the ability to absorb and maintain changes in environmental variables. In the transportation field, resilience may have several definitions. In the study of Freckleton et al., 2012, resiliency is defined as the ability of a transportation network to absorb disruptive events gracefully and return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame. In the literature, several studies focus on transportation networks and resilience.

On the other hand, many studies focused specifically on resilience during and after an extreme event. For example, W. Xu et al., 2024 analyzed the resilience of road networks to flooding. They used a Delphi method combined with an interpretative structure model and analytical network process to study how to build a model to improve the resilience of road logistics at risk of flooding. Gao et al., 2021 proposed an aseismic resilience evaluation method for an urban road network to improve the resistance and recovery ability of urban road networks facing earthquake disasters. Arango et al., 2024 proposed an extension of a Gis-based methodology for fire analysis to improve local resilience in managing road transport networks under wildfire hazards. Cinderby et al., 2024 explored the status of inclusive mobility and climate-resilient transportation in Africa, through a nested-scale approach. Some studies, on the other hand, analyzed a new dimension of road infrastructure resilience aimed at identifying the most critical links. For example, Kazmi et al., 2023 provided information about delays experienced by travelers and distances traveled when specific links are closed. They proposed a novel framework to analyze the resilience of urban transport networks, considering the dynamic role of links within the overall network, including their ability to accommodate additional traffic demand from other links. The model took into consideration parameters related to volume delay functions obtained from travel times during free-flow and peak hours. They took into consideration parameters such as demographic variables, geospatial data, traffic parameters, and infrastructure inventories. Chen et al., 2022 used the percolation theory to determine the minimum required performance of a road network and explore the spatial distribution of dynamic resilience based on traffic performance under traffic congestion. Kim et al., 2023 selected disaster resistance roads in urban areas that could maintain the functions of cities and can contribute to the increase of urban resilience using an eigenvector ratio of an adjacency matrix model. There are few studies related to resilience and tourism, for example the study of Ding et al., 2024 analyzed the impact of the COVID-19 pandemic on the resilience of the tourist economy, and the study of Roca Bosch and Villares Junyent, 2014 focused on methods to reinforce socio-ecological resilience for tourist destinations.

To the best of our knowledge, there are no studies concerning transportation network resilience in case of major events, such as concerts in the square, and related to cycling tourism. For this reason, we propose a resilience indicator for cycling tourism related to urban areas major events for tourist-oriented cities which we will elaborate on in the chapter 5.1.

1.4. The resilience of transportation networks

The development of sustainable mobility in the transport sector is crucial for ensuring an adequate quality of life for citizens. Promoting and facilitating travel within urban areas is both a priority and a major challenge for environmental, social, and economic sustainability. Urban congestion hinders potential economic growth and highlights the need for alternative solutions. It is worth noting that the presence of tourists at certain times of the year significantly changes transport demand, particularly in urban areas of cultural and landscape significance. Typically, these fluctuations in tourist flows occur over short to medium periods. As a result, the mobility behavior of users, especially residents, in terms of urban travel is directly affected by the increased presence of tourists in urban areas.

Tourism can be a catalyst for sustainable mobility, with significant public health benefits. The management, moderation, and redistribution of tourist flows are essential to maintain a balanced coexistence between citizens and tourists in urban environments. It is becoming increasingly evident that certain cities or urban areas are experiencing the phenomenon of overtourism, which has a high impact on the ecosystem. Therefore, preventing overtourism is an urgent task. The UNWTO defines over-tourism as "*the impact of tourism on a destination, or parts thereof, that excessively influences the perceived quality of life of citizens and/or the quality of visitors' experiences in a negative way*" (Duignan, 2019).

A recent study conducted in Italy in 2023, which included several small Italian municipalities, reported that 4 million tourists were concentrated in just over one square kilometer of Liguria. This tourist density is comparable to that of major tourist cities such as Florence and Venice (MIC-HUB commissioned by the Cinque Terre Park, 2024). Managing large tourist flows in cities for the benefit of both visitors and residents is a critical issue in the tourism sector. Therefore, the implementation of policies that promote inclusive and sustainable urban tourism can contribute to the management of the urban agenda and the achievement of Sustainable Development Goals (SDGs) (Department of Economic and Social Affairs of United Nation, 2024), not only in urban areas but also in the surrounding areas.

At this point, it is important to introduce the concept of urban resilience. Since the publication of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Pachauri and Reisinger, 2007), the climate debate has shifted from focusing solely on mitigation to including both mitigation and adaptation strategies (Frommer, 2013). Although climate change is a global issue that affects various human settlements, its impacts are expected to be most severe in cities (Sharifi and Yamagata, 2014). Today, most of the world's population lives in urban areas, and demographic forecasts indicate that nearly all future population growth will occur in these areas. Paradoxically, many of these urban areas are in regions vulnerable to many natural and human-caused hazards (Ernstson et al., 2010). According to (Sharifi and Yamagata, 2014), several themes such as infrastructure, security, environment, economy, institutions, and social and demographic can serve as a basis for developing a more integrated framework for assessing and improving the resilience of urban areas.

This study proposes a novel methodology to evaluate the resilience of urban road networks for cycle tourism through a dedicated efficiency indicator. This indicator captures the network's ability to sustain functionality and performance levels despite disruptions caused by planned events (e.g., major gatherings) or unforeseen circumstances (e.g., accidents, mechanical failures, extreme weather conditions). Such disruptions affect the ease and speed of route selection and, critically, the mode of transportation—a key dimension of efficiency that reflects the system's adaptability to changing conditions. These impacts extend beyond local citizens and residents to include tourists, whose numbers fluctuate significantly throughout the year, with pronounced peaks during the summer. To develop solutions consistent with sustainability principles in the transport and tourism sectors, it is crucial to adopt a methodology capable of swiftly identifying vulnerabilities and generating a performance or efficiency index for each segment of the urban road network, thereby ensuring reliable and adaptable mobility systems.

The concept of resilience refers to the ability of a city or region to respond to global threats such as climate change and land-use challenges. It is defined as the ability of a system to adapt, change, recover, and/or absorb internal or external shocks, and thereby ensure its persistence (Gaitanidou et al., 2017; Marchese et al., 2018). This concept is particularly useful for evaluating complex systems where dynamic interactions occur across multiple scales and factors, such as urban areas (Fernandes et al., 2017). Although resilience is often associated with climate or environmental risks, societies are also increasingly vulnerable to economic fluctuations (Ajibade, 2017; Boschetti et al., 2017; Sellberg et al., 2015; Sharifi and Yamagata, 2016). Therefore, urban systems must be prepared to adapt to unexpected and unprecedented changes (Ahern, 2011). Among the most frequently discussed threats in the literature on urban resilience and sustainable development are climate change and natural hazards (Jaroszweski et al., 2014; Leichenko, 2011; Meerow et al., 2016; Tromeur et al., 2012), which are becoming more frequent and intense, posing significant risks to years of development progress, particularly in emerging economies (Gallagher and Cruickshank, 2016).

The concept of road network resilience refers to the ability of a road network to recover from disruptions affecting one or more of its components. This characteristic depends on the structure of the network and the measures that can be taken to maintain or restore service following a disaster or other form of disruption. In other terms, resilience can be defined as the ability of a system to withstand disruptions and recover its original function after a loss of performance (Calvert and Snelder, 2018).

Today, there is an urgent need to ensure the implementation of safe infrastructures to support sustainable development and allow for an appropriate environmental and social transition, especially in light of new transport paradigms and high-frequency hazard events. In this context, it is essential to study and invest in the resilience of transport infrastructure, especially in high-density cities. Sustainable urban transport solutions can include several innovative solutions and incentive strategies, such as promoting and prioritizing the use of bicycles over cars (e.g., in Copenhagen). Further examples include the introduction of dedicated cycle and bus lanes, the construction of underground parking facilities not only for motor vehicles but also for micromobility vehicles (e.g., in Utrecht), and the use of cable cars for hilly urban areas. It is also important to consider integrated transport solutions, such as multimodal systems that combine cycling with public transport (F. Morgese et al., 2024).

In the study conducted by (Kakati et al., 2024), the objective was to identify the most optimal sustainable approach to improve and rationalize the urban transport system. The results obtained in the city of Mersin, Turkey, provided valuable support for decision-makers in formulating strategic plans to implement effective solutions that promote a more sustainable urban environment. The study highlighted the key quality factors related to public bus transport provision such as tractability, fare, and service and transport factors. These factors can be expanded to consider sub-factors for each main criterion, and potential alternatives that may vary depending on the specific case study and the operational transport model selected.

In the study proposed by (Frazier et al., 2013), a set of place-specific indicators was developed for the assessment of baseline resilience in Sarasota County, Florida. The authors suggested that these indicators should be weighted differently based on the context. Among the primary criteria identified as part of an urban resilience assessment framework are road connectivity, pedestrian connectivity, sidewalks connecting to public transport, accessible connections to evacuation routes, clustering of interdependent infrastructure, redundancy in infrastructure, urban form and size, building density, independent infrastructure, mixed-use development, variability, and spatial heterogeneity, avoidance of floodplains, frequent public transit schedules, arterial road miles per square mile, and vehicle ownership.

Recent disruptive events have shown that network failures not only have catastrophic consequences but also hinder the recovery of network performance (González et al., 2016; Xie et al., 2023). The recovery of overall system functionality is often compromised due to the complex interrelationships between network systems. For example, when a subway system shuts down due to an accident, affected passengers may be transferred to nearby bus stops to reach their destinations. However, travel delays on the bus network may be exacerbated by the sudden influx of passengers and severe traffic congestion. To mitigate such threats from disruptive events and complex network interactions, the resilience of the overall system has been a focus of recent research (Bešinović, 2020; Loo and Leung, 2017; Mattsson and Jenelius, 2015), where resilience is described as the ability of networks to withstand, recover, and adapt to maintain functionality after disruptions. As a result, significant research has been conducted from various perspectives to assess network resilience during disruptions (Hossain et al., 2019; Lu, 2018).

Current research on interdependent networks examines different types of interdependencies between networks (Lu et al., 2022; Ouyang, 2014) and qualifies the consequences of cascading failures across networks (Lu and Lin, 2019). When two interdependent networks function together, their relationship is typically bidirectional, which can significantly affect the resilience of both networks during disruptions. However, the resilience characteristics of interdependent networks are often not fully captured or interpreted in terms of the characteristics of individual networks. As a result, the impact of two-way dependencies on the resilience of interdependent networks remains under-studied.

As an interdisciplinary concept, resilience has been defined in various ways across different fields. In general, system resilience is often measured using the resilience triangle, which describes the performance losses of a network over time and its recovery process to restore a predefined level of performance after disruptions (Bruneau et al., 2003). In the study provided by (P. C. Xu et al., 2024), the authors conducted a resilience analysis of interdependent networks by assessing the impact of station and failure events in interdependent transit networks. Furthermore, the authors proposed a resilience model to evaluate the resilience of interdependent networks in the event of failures by identifying critical nodes based on network dynamics. This methodology explicitly captures not only the topological characteristics of the network but also dynamic factors such as rerouted flows, station capacity, and transfer delays over time. The impact of network interdependencies on resilience varies depending on factors such as topology, functional similarity, flow volume, location, and degree of interdependence. Failures at stations or bus stops with high topological interdependence have a significant impact on the resilience of interdependent transport networks. In addition, the authors stated that resilience is notably affected by the heterogeneity of node importance, especially during subway station and bus stop closures. Interdependent subway and bus networks are difficult to restore when key passenger transfer stations are closed following an accident because alternative subway lines and dependent bus stops often have limited capacity.

In the study provided by (Kazmi et al., 2023), the authors developed a framework to evaluate the role of a link in the overall network performance. The framework extends the existing methodologies in the literature by evaluating network resilience through two key aspects: the ability of a link to affect the system when it is disrupted, and its ability to support the system when other links experience failures. In practice, this approach allows for the identification of both the least and most resilient links by considering resilience as a function of operational characteristics (e.g., flow, congestion) and additional qualities such as network vulnerability and betweenness centrality. Moreover, the study found that high-speed links located on the periphery of a city are particularly critical. It also emphasizes the importance of links that connect larger urban areas separated by natural topographical features.

In order to promote sustainable development, urban planners need to establish strategies that sustainably optimize land use in alignment with public transport initiatives. However, public transport faces various threats that can disrupt its functioning, making it essential to discuss the concepts of resilience and vulnerability. In this context, resilience-based strategies provide a holistic approach that considers both predictable and unpredictable threats (Lomba-Fernández et al., 2019).

Among the aforementioned studies, and to the best of the authors' knowledge, there are no studies that have evaluated the resilience of a road network from the perspective of cycle tourism. This motivated us to fill this gap by assessing the resilience of urban cycling infrastructure during unforeseen events. We consider efficiency to be a key aspect of resilience; indeed, one way to evaluate road network resilience is to assess the efficiency of a given event resulting from a choice made or a phenomenon occurring. Specifically, we focus on scenarios where a road link (or group of road links) is closed along a route allowed for cyclists, aiming at limiting disruption and maintaining cycling accessibility.

1.5. DEA application models for road network resilience assessment

In their seminal study "Measuring the Efficiency of Decision-Making Units", Abraham Charnes, William W. Cooper, and Edwardo Rhodes (CCR) developed the first model of Data Envelopment Analysis (CCR-DEA) (Charnes et al., 1978). In general, DEA is a non-parametric operations research and economics tool that assesses how effectively decision-making units (DMUs) use linear programming techniques to convert inputs into outputs. Numerous studies have applied this concept to the field of transportation, resulting in extensive literature.

There are numerous contributions in the literature on the evaluation of the resilience of a road network using different mathematical models. Several researchers have utilized DEA-based methodologies to measure resilience in terms of performance within transport networks. Among several studies that applied DEA-based methodologies in suburban environments, e.g., (Babaei et al., 2022; Djordjević and Krmac, 2019; García-Palomares et al., 2018; Rahman et al., 2023; Shah et al., 2017; Simić et al., 2020; Vrtagi´cvrtagi´c et al., 2021; Yi et al., 2012; Zeng and Yang, 2014), we focused on the most relevant studies applied to the urban context. For instance, (Fancello et al., 2013) evaluated through the DEA model the efficiency of road networks of different cities in Italy. The authors used as input the main characteristics of road networks, such as traffic flow, accessibility, and safety. The study proposed by (Caggiani et al., 2021) examined the use of bike-sharing systems (BSS) in Malmö, Sweden, considering trends in BSS use, traffic patterns, land use, and socio-economic factors. An evaluation of the effectiveness of BSS in Seoul, South Korea, was conducted in a study proposed by (Hong et al., 2020) using a two-stage bootstrap DEA methodology. The authors employed the ratio of cycle pathways and the number of available bicycles as input variables, while the balance ratio and bicycle turnover were considered as output variables. The results demonstrated the effectiveness of BSS in residential and educational areas of the city, while inefficiencies were evident in commercial, industrial, and administrative districts. Furthermore, (Prencipe et al., 2022) evaluated the micromobility safety-related efficiency of urban areas using a DEA methodology in the city of Bari, Italy.

Each zone in the study area was divided into grids and assigned an efficiency score ranging from zero to one. This score is generated using variables relevant to micromobility accidents, such as road intersections, vehicle speed, and the presence of bicycle lanes.

Other studies have applied the DEA methodology to the tourism sector. For instance, the research by (Chen et al., 2018) conducted a performance evaluation of tourism service quality in Taiwan using DEA with input and output constructs to estimate service quality efficiency. The empirical results of the technical efficiency estimation showed that the domestic tourism market is competitive but still needs improvement in service quality. The primary objective of the study proposed by (Huang, 2018) was to establish a hybrid network DEA model to measure integrated and divisional performance within the supply chain. The main difference between the proposed DEA model from previous network models lies in its assumption of variable and semifixed inputs, which are measured using radial and non-radial assumptions in mathematical programming. Unlike conventional supply chain analysis models, the proposed model accommodates different types of input, treating variable and semifixed factors as radial and non-radial inputs, respectively. In addition, the model defines overall efficiency based on radial ratios and slacks across all divisions, thereby representing the integrated performance of the tourism supply chain. This overall efficiency can be further decomposed into several inefficiency indices to explore the sources of inefficiency. Similarly, (Chaabouni, 2019) aimed to examine the efficiency of tourism and identify factors influencing this efficiency based on panel data from Chinese provinces from 2008 to 2013. The results indicated that the DEA results tend to overestimate tourism efficiency in these provinces during the sample period. In the subsequent analysis, the authors evaluated the effects of trade openness, education level, number of hotels, degree of urbanization, and climate change on tourism efficiency. In particular, education level and geographical location were found to have a significant negative impact on tourism efficiency. This research provided several insightful management implications, suggesting that policymakers and governments should develop an appropriate framework for allocating funds to enhance tourism efficiency. According to (Cracolici et al., 2007), to properly assess the utilization of existing tourism capacity or infrastructure, it is crucial to consider the different socio-economic categories of tourists, the attractiveness of tourist sites, and the transport and communication characteristics between origin and destination. In the study conducted by (Wu et al., 2023), sustainability and competitiveness were analyzed through efficiency measures using DEA. The authors constructed a function to define a tourism development index and a tourism sustainability index. The results indicated that the traditional measure of tourism efficiency, the tourism development index, fails to account for undesirable outputs characterized by negative impacts, such as carbon emissions from travel, leading to overestimations of efficiency. However, this study underscored several practical implications: the increasing competition among tourism destinations necessitates that industry managers determine the optimal allocation of resources to promote sustainable urban tourism development. In light of the global call for 'carbon neutrality,' it is essential to consider the negative impacts of tourism on the natural environment to enhance the competitiveness of tourism destinations. Finally, (Lozano-Ramírez et al., 2023) evaluated the sustainability efficiency of tourism across 27 EU countries from 2015 to 2019. The proposed approach was based on the DEA methodology and used several economic, social, and environmental indicators. Efficiency scores and targets for each country in each year were calculated and discussed, providing valuable insights, including the identification of countries with best practices in tourism sustainability, which is critical for the challenging task of revitalizing the sector and resuming the upward trend in tourism sustainability observed before the pandemic.

Among the various types of tourism, cycle tourism is a rapidly growing sector. This mode of travel is becoming increasingly accessible, largely due to the e-bike widespread. However, certain basic conditions must be in place for it to prosper: a well-structured network of routes, infrastructure for e-bike charging, and well-equipped accommodation facilities that address the needs of cycle tourists (Morgese et al., 2024). In 2023, over six million tourists visited the Apulia region in

Italy, with the city of Bari emerging as the second most visited city, attracting over five thousand arrivals. The city of Bari has been one of the most popular destinations in Europe in recent years, recording over one million visitors the last year (Pugliapromozione, 2023). This motivated us to apply the proposed methodology to the city center of Bari, which is the most frequented by tourists. It is worth noting that compared to other Italian regions, Apulia region captures approximately five percent of national tourists and about four percent of cycle tourists opting for a sustainable cycling experience in Italy (ISNART – Istituto Nazionale Ricerche Turistiche/Legambiente Onlus, 2023). In particular, we applied the input-oriented CCR-DEA to the city center of Bari for the assessment of road network resilience from a cycle tourism perspective through a specific indicator, as discussed in Section 5.2.

2. Sustainable Tourism Services

2.1. Analysis of Bike-friendly Services for Sustainable Tourism: the Case of Apulia Region.

Nowadays, experiential tourism, active tourism, sports tourism, and slow tourism have witnessed a remarkable surge in popularity, attracting a significant segment of travellers seeking unique and immersive experiences. These forms of tourism encompass activities that align with the principles of sustainability: the economic dimension, since it is an activity able to generate revenues for the administrations; the environmental one, being an ecological activity, fostering respect for nature and all living beings; the social one, since new paths provides both new transport infrastructure and possibility for recreation also for the local population. Cycling tourism is the main segment of this phenomenon, leading decision-makers to foster the financing and building of new recreational cycle paths at local and national levels.

To ensure the success of cycling tourism initiatives, the approval and involvement of the public and citizens are crucial. Traditional decision-making methods may not fully capture the perspectives and preferences of these key stakeholders, necessitating the adoption of participatory procedures for evaluation. By employing participatory approaches, decision-makers can incorporate a wide range of voices, resulting in more informed and inclusive decision-making processes. Based on this premise, this study aims to develop a comprehensive framework for evaluating the implementation of cycling tourism services; CAWI (Computer Assisted Web Interviewing) is employed to gather insights from city administrators who play a pivotal role in the planning and implementation of cycling infrastructure and services. The Apulia region in Italy is selected as a case study due to its unique geographic characteristics, including a predominantly flat terrain with limited hills and its abundance of naturalistic attractions. Moreover, Apulia has recently launched the "Puglia Bike Destination strategy" a strategic plan designed to enhance cycling tourism throughout the region. A survey, developed by the author Fulvio Morgese et al., was conducted across all municipalities, local authorities, and trade associations in Apulia to comprehensively assess the existing cycling infrastructure, facilities, and equipment. The survey was designed to explore the willingness of stakeholders to implement new cycling services, particularly bike-sharing, as well as to gather insights into the challenges, opportunities, and specific requirements associated with such initiatives. The results will shed light on the existing infrastructure gaps, potential benefits, and challenges identified by the stakeholders, providing a comprehensive overview of the region's readiness and interest in promoting cycling tourism.

Apulia ("Puglia" in Italian language) is a region located in south Italy, which has been increasing its tourism attraction in the last years. In 2023, the Apulia Region experienced a resurgence in long-distance tourist markets, notably from Australia and the United States, with an increase of over 50,000 tourists during the first eight months compared to the previous year (Pugliapromozione, 2023). A total of 16.4 million tourists visited the Apulia region (Italy) in 2023; the growth in international tourism was +22% for arrivals and +16% for visitors compared to 2022. The overall balance of tourists at the end of the year stood at +8% for arrivals and +4% for visitors; the internationalization of arrivals (the share of foreigners in the total) rises from 29% to 34% in a year, even though the trend in national tourism has remained more or less static (SPOT, 2024).

In this regard, the Apulia Region recently tasked ASSET - Agenzia per lo Sviluppo EcoSostenibile del Territorio (an agency that operates in support of the Apulia Region in the fields of mobility, urban quality, public works, ecology, and landscape) to establish a working group to draft the Regional Bicycle Mobility Plan (ASSET - Regione Puglia, 2020). This plan serves as a planning document for the regional bicycle network and also as a tool for landscape enhancement and tourism promotion. Following the guidelines of the National Bicycle Mobility Plan, the Regional Bicycle Mobility Plan aims to create a network of cycleways and bicycle paths that traverse the entire regional territory, connecting the region's main urban, natural, and cultural centers. To encourage significant growth in bicycle travel, proper planning at different scales is deemed necessary. This involves creating a hierarchical and functional bicycle network system, ensuring effective modal integration, providing concrete permeability of modal interchange nodes with guided and signposted routes for access to boarding, and eliminating physical obstacles with ramps, slides, and elevators. The specific objectives of the Regional Bicycle Mobility Plan of Apulia include developing bicycle tourism in Apulia, identifying the backbone routes of a regional bicycle network, establishing design criteria for the realization of cycleways, promoting multi-level cyclability, incentivizing bicycle mobility for both recreational and systematic travel purposes (such as home-school and home-work commutes), and collaborating with other entities that own linear infrastructures in the territory to achieve the objectives of bicycle mobility in the medium and long term. The plan includes a mapping of bicycle tourism routes in a booklet entitled "Puglia Bike Destination". As part of this plan, a mapping of bicycle tourism routes was compiled into a booklet titled "Puglia Bike Destination." In November 2022, during the national assembly of the Association of Italian Municipalities (ANCI) in Bergamo, a cooperation agreement was signed between the regional delegation of ANCI Puglia, the Department of Tourism and Culture of the Apulia Region, and the regional tourism agency "Pugliapromozione". This agreement committed to fostering the development of slow and sustainable tourism models, experiences by foot, bicycle, and in contact with nature, to enhance and promote the destination of Apulia and lesser-known tourist attractions in the region. One significant contribution initiated was the creation and administration of a questionnaire developed in collaboration with the Polytechnic University of Bari, which was addressed to Apulian municipalities belonging to the ANCI Puglia network of municipalities.

In the following sections, we will present and compare the results of the two main initiatives: the "Puglia Bike Destination" booklet and the questionnaire administered to Apulian municipalities.

2.2. The Survey and Booklet "Puglia Bike Destination"

The questionnaire was administered through a Google Form delivered by certified mail to the relevant offices for each municipality in the Apulia region. It consists of several questions divided into 12 sections (S); the main sections analyzed in this work are as follows:

- S1: Identification data (name of municipality, province, competent alderman, email, phone, operational contact number).
- S2: Presence of bicycle routes. This section includes questions regarding the presence of protected urban/suburban bicycle paths and their length. Municipalities were also asked to share any relevant files (e.g., GPX/KML/SHP format) of their routes.
- S3: Transport Planning tools. Respondents were asked to declare if their town had a Sustainable Urban Mobility Plan (SUMP) or a Bike Municipality Plan (in Italian "Biciplan").
- S4: Bike sharing services. This section investigates the presence of a bike-sharing service in the municipality (currently or in the past); if present, municipalities were asked to specify if the system operates on a free-floating or station-based modality.
    - S4.1 (existing bike sharing service): Operation of the service. Municipalities were requested to explain and comment on how the bike share service in their municipality operates.
    - S4.2 (bike-sharing service interrupted): Municipalities were asked to list and comment on the main problems encountered that led to the interruption of the bike-sharing service.
    - S4.3 (bike-sharing service never existed): This section addresses municipalities that have never had a bike-sharing service. Questions in this section regard the potential activation of a bike-sharing service in their territory, including: (i) the possibility of managing the service with a dedicated office; (ii) being the promoting/leading municipality of a bike-sharing service among municipalities within a 10 km radius; (iii) preference towards

being a partner of a consortium of cities with a unique bike sharing service; (iv) unwillingness to adopt a bike sharing service.

- S5: Presence of cycling-friendly accommodation (e.g. bike hotel)
- S6: Presence of bike station; if yes, type of structure, quantity, characteristics, and other useful information.
- S7: Presence of bike workshops; if yes, type of structure, quantity, characteristics, and other useful information.

The booklet developed by the author Fulvio Morgese and entitled "Puglia Bike Destination" (fig. 6) contains a mapping of 56 medium- and long-distance routes that cross the entire regional territory, connecting the main urban centres and major points of tourist interest.

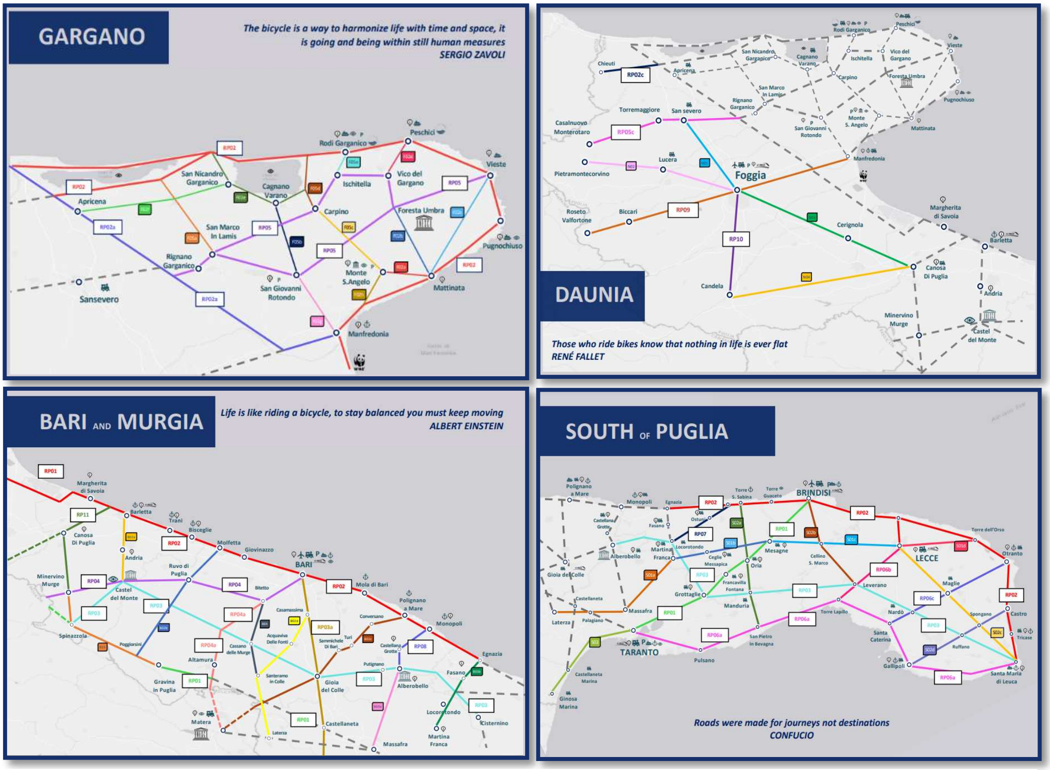


Figure 1 The four areas in the booklet "Puglia Bike Destination" (source: http://asset.regione.puglia.it/assets/images/cicloturismo/ASSET_ENG_v2.pdf).

These maps provide information on the distance in kilometres, altitude, difficulty level of the route, and a historical-cultural description of the places along the route. The territory was subdivided into four macro areas of region: 'Gargano', 'Daunia', 'Bari and Murgia', and finally the 'South of Apulia'. Additionally, each itinerary in the booklet includes a Google MyMaps page with the mapping of the route on Google Maps for easy reference.

2.3. Result of the analysis

The figure 2, developed by the author Fulvio Morgese with Google MyMaps, shows the location of the different municipalities of Apulia Region that responded to the questionnaire.

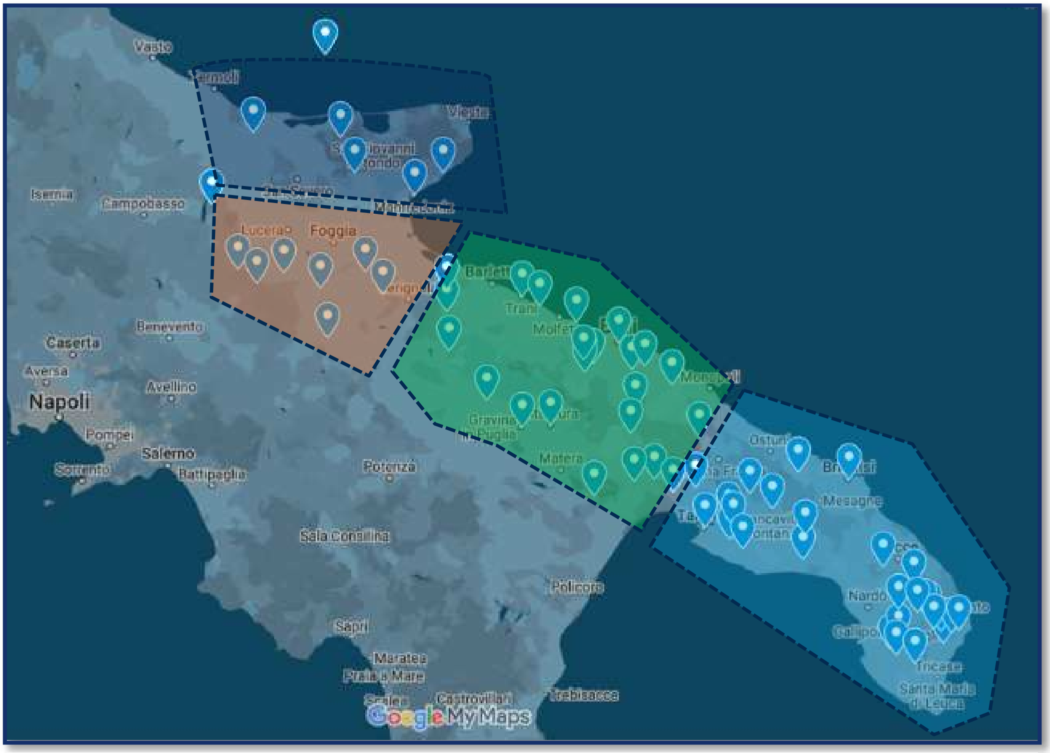
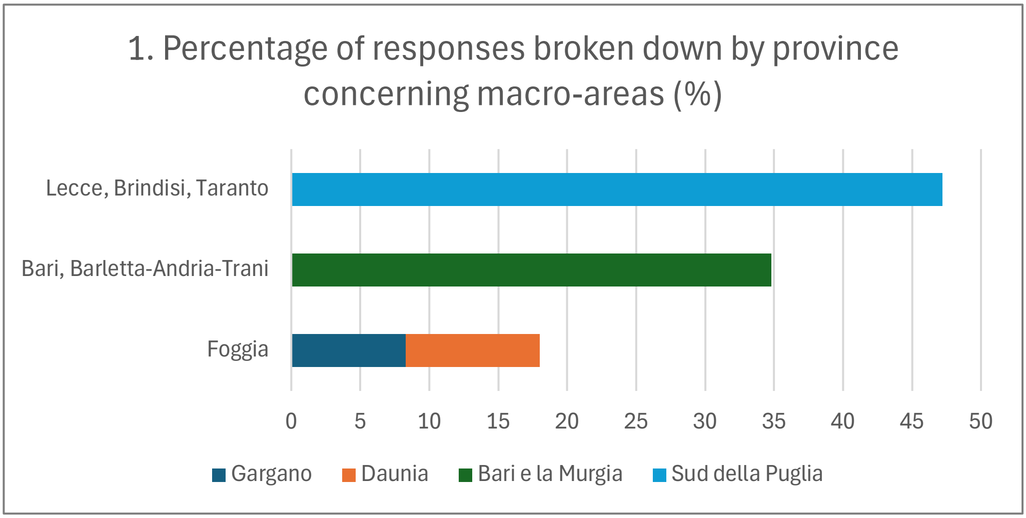


Figure 2 The four areas in the booklet "Puglia Bike Destination" (source: http://asset.regione.puglia.it/assets/images/cicloturismo/ASSET_ENG_v2.pdf).

As evident from the data, the territorial distribution of responses is notably consistent, with a total of 72 municipalities participating as of May 2024. Notably, each province within the Apulia Region is represented, showcasing a diverse engagement across the region. 22,2% of respondent cities are located in the province of Lecce, 23,6% in the province of Bari (regional capital), 20,8% in the province of Foggia, 16,7% in the province of Taranto, 8,3% in the province of Brindisi and the remainder in the province of Barletta-Andria-Trani. Details on the distribution among the four macro-areas can be found in Table 1 and the results are depicted in graph 1 below.

Table 1 Percentage of responses broken down by province concerning macro-areas (%).

	Gargano	Daunia	Bari Murgia	Sud Puglia
Foggia	8,3	9,7	-	-
Bari, BAT	-	-	34,8	-
LE, BR, TA	-	-	-	47,2



In the second section of the questionnaire, about bicycle routes, 36.1% of the municipalities reported the presence of urban and/or suburban itineraries on protected bicycle paths, while 31.9% indicated their absence in their municipality.

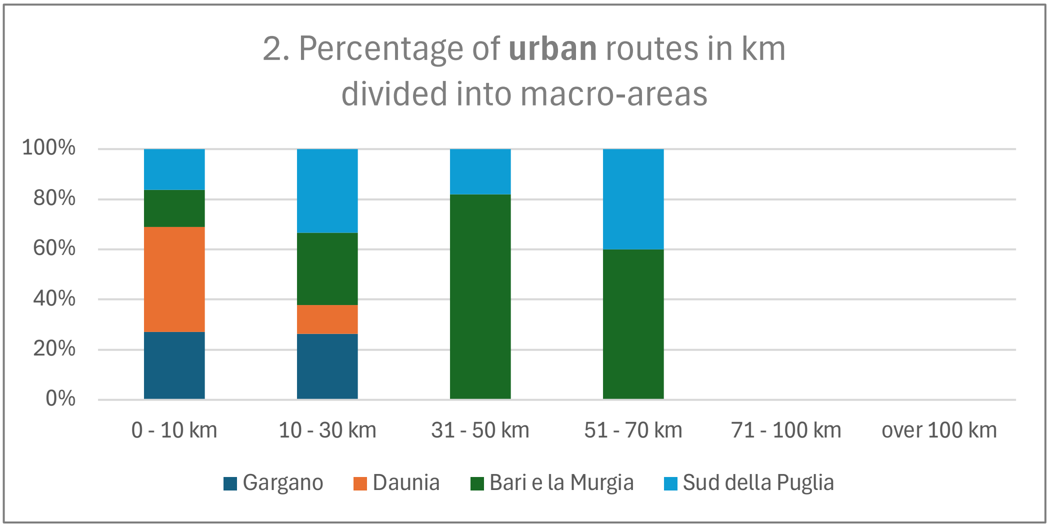
Additionally, 12.5% specified that such paths exist solely in suburban areas, and 19.4% confirmed their presence in both urban and suburban settings.

Continuing with the section, municipalities were asked about the range in kilometres of existing routes:

- Regarding urban routes, 84% reported lengths between 10 to 30 km, 8.7% between 31 to 50 km, 4.3% between 51 to 70 km, and 2.2% over 70 km, categorized by macro-areas as shown in Table 2 and the results are depicted in graph 2.

Table 2 Percentage of urban routes in km divided into macro-areas (%).

	Gargano	Daunia	Bari Murgia	Sud Puglia
0 - 10 km	66.6	77.8	40.9	30.3
10 - 30 km	16.7	11.1	45.5	57.6
31 - 50 km	16.7	11.1	-	9.1
51 - 70 km	-	-	-	-
71 - 100 km	-	-	9.1	3.0
over 100 km	-	-	4.5	-

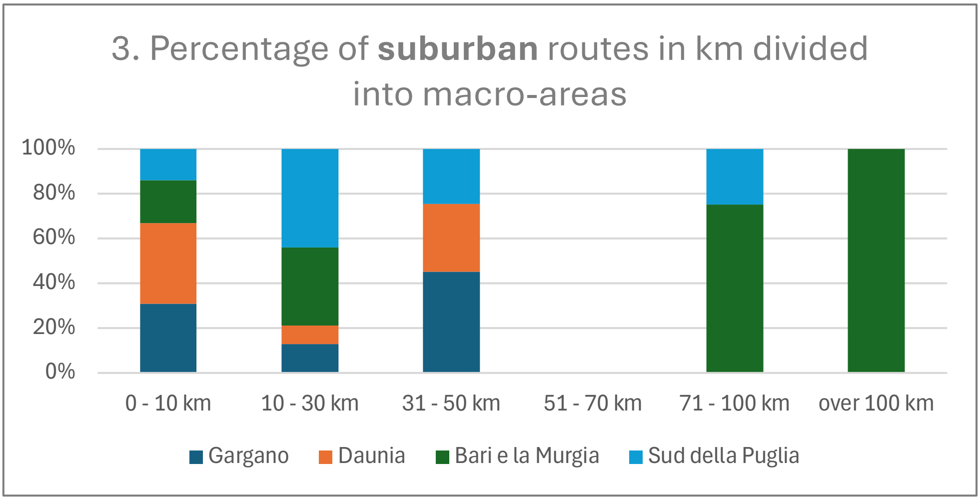


- Concerning suburban routes, 76.2% indicated lengths between 10 to 30 km, 11.9% between 31 to 50 km, 4.8% between 51 to 70 km, and 4.8% over 70 km, segmented by macro-areas as displayed in Table 3 and the results are depicted in graph 3.

Of these routes, 66.7% of the municipalities subsequently transmitted the routes in Google or GPX format to the designated email address, while 33.3% attached them directly in the questionnaire slot.

Table 3 Percentage of suburban routes in km divided into macro-areas (%).

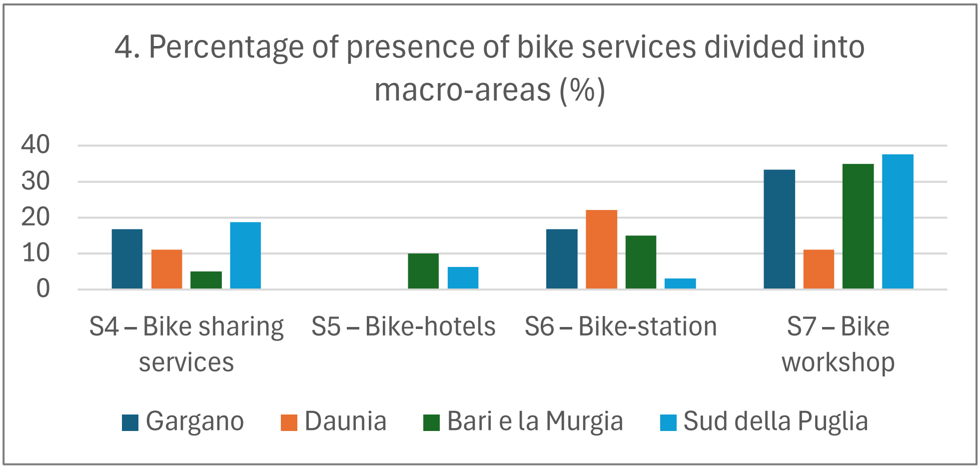
	Gargano	Daunia	Bari Murgia	Sud Puglia
0 - 10 km	66.6	77.8	40.9	30.3
10 - 30 km	16.7	11.1	45.5	57.6
31 - 50 km	16.7	11.1	-	9.1
51 - 70 km	-	-	-	-
71 - 100 km	-	-	9.1	3.0
over 100 km	-	-	4.5	-



In terms of available planning tools, 69% of municipalities have not yet adopted a SUMP, and 76.4% have not adopted a BICIPLAN. S4 addresses the topic of bike sharing by exploring various details related to the service: 70.8% of municipalities indicated that the service has never existed, 15.3% stated that the service exists in a station-based format, 9.7% reported that it currently does not exist but has previously operated in a station-based format, and 4.2% mentioned that it currently does not exist but was previously available in a free-floating form. Among municipalities where the service has never existed, 25% stated that they have a dedicated office and believe they can independently manage the service, 38.9% believe they can act as the promoting/leading municipality among neighbouring municipalities within a 10 km radius, 23.6% believe they are not capable of leading an aggregation to manage the service, and 6.9% consider the bike sharing service not useful. Regarding S5, 92.8% reported the absence of cycling-friendly accommodations in their municipality. Concerning S6 bike stations, 87% of municipalities stated the absence of any bike stations in their territory, 11.6% indicated the presence of at least one, and 1.4% reported their presence but mentioned that the project was discontinued. In S7, municipalities were asked about the existence of bike workshops: 64.3% answered negatively, 34.3% affirmed their existence, and 1.4% stated their presence but mentioned project discontinuation. Statistics on the presence of services have been further explored by macro areas in Table 4, graph 4.

Table 4 Percentage of presence of bike services divided into macro-areas (%).

	Gargano	Daunia	Bari Murgia	Sud Puglia
S4 – BSSs	16.7	11.1	5.0	18.8
S5 – Bike-hotels	-	-	10.0	6.3
S6 – Bike-station	16.7	22.2	15.0	3.1
S7 – Bike workshop	33.3	11.1	35.0	37.5



Recognizing the potential number of individuals who may utilize the available cycle routes is crucial at various levels, ranging from a tourism perspective to urban planning. The popularity of one route over another can guide different strategic interventions, including constructing additional facilities, offering more activities, and, primarily from an engineering standpoint, prioritizing interventions along that route. With this in mind, the objective of this additional data collection was to assess the number of visitors to the Google MyMaps web pages of cycle routes featured in the Puglia Bike Destination booklet.

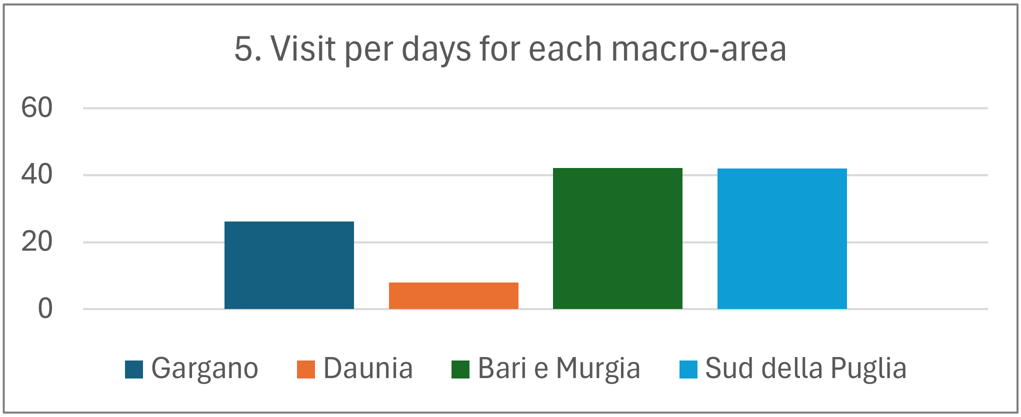
Data on visitors/clicks after about 400 days after the website launch (Table 5) are interesting and reveal some insights about the preferences and choices that cycle tourists would seek; for the 56 proposed routes, the website achieved over 52 thousand views, with an average of 130 clicks per day. The most clicked route belongs to the macro area of "Bari e la Murgia" and it is called "Ciclovia dell'Acquedotto Pugliese" with about 3000 clicks. This same macro area is also asserted to be the most clicked part of Apulia with a total of over 21 thousand clicks. It is followed by the "Gargano" with over 15 thousand views, the "South of Puglia" with over 13 thousand clicks, and finally the Daunia with about 2500 views. Another interesting indicator is the one related to the average visits per day, which still established "Bari e la Murgia" as the most visited route but shows that the second most viewed itinerary is the one related to the south of Apulia “Sud della Puglia”, which route Google MyMaps page has been released 6 months later.

The analysis of the results coming from the two instruments allows to depict interesting insights. Data in Table 2 and 3 suggest that shorter routes (max 30 km) are the most present in both urban and suburban areas, which might be interpreted as a scarce connectivity of the comprehensive regional cycling network. Moreover, statistics on the presence of cycling services in Table 5 show that all types of services are available only in less than half of the municipalities that responded to the questionnaire, in each of the four areas. This result, although limited to the respondents, shows that there is still need for economic investment in the Apulia region on this type of services to promote cycling tourism.

A positive signal in this direction is given by the comparison of the results of the two initiatives. Looking at Table 4, it is interesting to notice that the macro areas “Bari e la Murgia” and “Sud della Puglia” are the only zones where all four types of cycling services are available; this might be one of the drivers that make them emerge as the most “clicked” in graph 5, hence the most attractive to tourists, among all the four areas. Their municipalities, indeed, declared the presence of bike hotels, probably making them attractive destinations for cycling tourists, although the presence of bike-sharing services in “Bari e la Murgia” is esteemed as the lowest.

Table 5 Date of launch, date of report, total views and n. of days elapsed for each macro-area.

	Launch date	Report date	Total clicks	n. days	Visit / day
Gargano	09.07.2022	26.02.2024	15550	597	26.0
Daunia	22.04.2023	26.02.2024	2440	310	7.9
Bari Murgia	17.10.2022	26.02.2024	20937	497	42.1
Sud Puglia	22.04.2023	26.02.2024	13028	310	42.0



Overall, the first results coming from the two initiatives are informed by data from both the demand (i.e. website clicks) and supply (survey to administrators) sides of cycling tourism. Using such data and others from similar initiatives could help decision makers to enhance the formulation of a more effective cycling tourism strategy. This could mitigate the risks associated with the emergence of unforeseen

demands, unprepared services, and the sudden influx of tourists, thereby ensuring a sustainable and resilient tourism development. Future research could aim to reinforce these findings by investigating the preference of cycling tourists for the different type of services.

3. The study area for the application of indicators

3.1. The city of Bari

Located in the southern part of Italy, the city of Bari is the capital of the Apulia region. With about 316,000 inhabitants and an area of 116 km^2, this popular destination is frequented by worldwide tourists. Tourists and residents alike explore the ancient heart of the city, known as “Bari Vecchia,” characterized by a maze of narrow streets. The city of Bari (Italy) is the most visited city in the Apulia region with over 380,000 arrivals and has been one of the most popular destinations in Europe in recent years. It registered about 1 million visitors from January to October 2022. Bari becomes the second most visited city in the Apulia region with over 515,498 arrivals in 2023 and has been one of the most popular destinations in Europe in recent years. It also registered 1,038,067 million visitors in 2023. Tourist flows are mainly from France and Germany, which in 2022 showed increases of +36% and +6% respectively compared to 2019. In addition, 54% of all tourists stay in medium to high quality hotels (38% in 4-star hotels in particular), while among non-hotel structures, B&Bs receive the greatest numbers (11% of total accommodation), followed by room rentals (7%) and holiday homes and apartments (5%) (Pugliapromozione, 2023).

Attractions in Bari's old town include numerous churches, such as the Basilica of St. Nicholas and the Cathedral of San Sabino, as well as a magnificent medieval fortress, the longest waterfront in Italy, and a plethora of culinary specialties. The major POIs in the city of Bari are located around the old town. These facilities are located near the port and seafront, and just 15 km from the airport. The city is characterized by a continuous flow of tourists throughout the year and especially during the summer months. In this context, it is effective to move around using micromobility, such as bikes or e-scooters, private or shared.

3.2. The metropolitan area of Bari

This area (Figure 3, developed by the author Fulvio Morgese with software QGis) has 1.26 million inhabitants and covers an area of 3,825 km². It is composed of 41 municipalities among which stands out the regional capital that is the city of Bari with over 315,000 inhabitants. The metropolitan area of Bari includes several municipalities and villages of strong historical and cultural interest, such as the municipality of Gravina considered one of the oldest cities in the world to be inhabited, with settlements dating back more than 10,000 years, the city of Altamura that preserves intact bones of Homo Neanderthalensis dated between 128,000 and 187,000 years ago.

The towns that still turn out to be the best known in the world today are Polignano a Mare, whose historic center spreads out on a rocky outcrop overlooking the sea carved out by the waters that run through "Lama Monachile" to meet the clear blue sea, and the town of Alberobello, the city of "trulli", singular conical stone houses belonging to the World Heritage Properties.

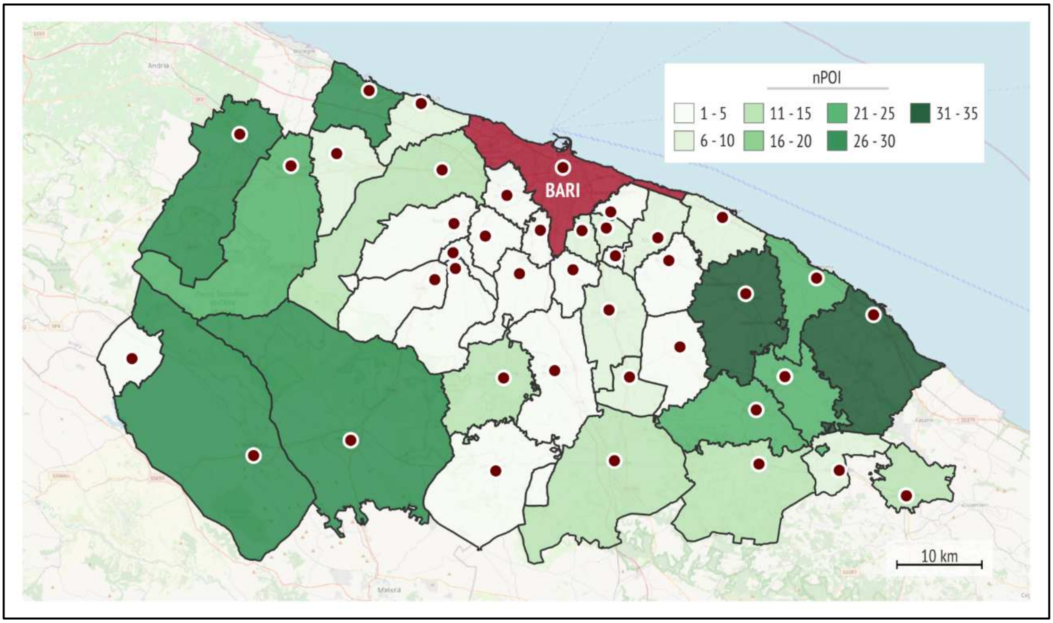


Figure 3 Metropolitan area of Bari (map data OpenStreetMap openstreetmap.org/copyright).

The main city of this area is Bari that is one of the most visited cities in the Apulia Region with over 873,000 tourist arrivals in the first 8 months of 2023. In the same period, the city of Bari becoming one of the most popular destinations in Europe in recent years. It registered about 60,000 visitors with an average of 130 thousand overnight stays in the city in October 2023 alone.

In the Apulia Region, 2023 marks the recovery of long-haul tourist markets with tourists coming mainly from Australia and United States, with an increase in the first eight months of 2023 of over 50,000 tourists compared to the same period of the previous year. The attractiveness of tourists from France, Poland, Brazil and Canada along with other ones from North-eastern European countries (Romania, Lithuania, Bulgaria, Hungary and Slovenia) is also high. Tourist flows from South America are also growing, particularly from Brazil (Pugliapromozione, 2023).

4. Cycle Tourism Accessibility

4.1. A Cycling Indicator for Tourism Accessibility Evaluation in Urban Areas

There is no doubt that the tourist industry is now a key factor in the perception of cities from cultural, economic, and social points of view. Micromobility plays an important role in providing intelligent, fast, and sustainable travel from accommodation facilities, such as hotels and bed and breakfasts (B&B), to locations of various attractions. In particular, bikes are one of the most widely used means of transportation in the city. They can be private property, provided by private entities, or rented from shared systems. Therefore, it is fundamental to identify the level of bike-friendliness in the city to improve sustainable tourism. For this purpose, factors such as the existence and safety of bicycle infrastructures and the presence of sharing systems are taken into consideration.

In this chapter, we propose a first cycling indicator for tourism accessibility with the aim of defining the level of bike- friendliness through numerical values related to a specific city zone. The first proposed indicator has positive values, and it is greater the higher the level of bike-friendliness. Municipal councils may have an interest in increasing these values, especially in zones where they are very low. The indicator can also be applied to other sustainable micromobility systems, such as e-scooter sharing. It was applied to the city of Bari (Apulia, Italy) and the results are interesting and highlighted zones in which it is necessary to increase tourist bike-friendliness.

The indicator, named Bike Tourism Index (BTI_i), related to a specific city zone i. This indicator is calculated taking into consideration several factors:

- cycling infrastructures: the presence of cycle lanes and road intersections with and without traffic lights.
- presence of bike sharing systems
- locations of the various accommodation facilities: hotels, B&Bs etc.
- locations of the various cultural attractions or Points-Of-Interest (POIs) and related tourism services (nature, sport, gastronomy and food, culture and

places of worship, squares, theatres, museums, major events, commerce and entertainment etc.)

- distances between accommodation and POIs

BTI_i summarizes tourist bike-friendliness from all accommodation in the considered i-th zone to all the POIs in the area under study. The expression is as follows:

$$BTI_i = \frac{\sum_{o_i=1}^{n_i}\sum_{d=1}^{m}\frac{1}{wd_{o_id}}*rel_d*\left(s+\frac{ntl_{o_id}}{int_{o_id}}\right)*\left(1+\frac{\frac{bs_{o_i}+bs_d}{2}}{bs_{max}}\right)}{n_i}$$

where:

- n_i is the total amount of accommodation (origins) in zone i;
- m is the total number of POIs (destinations) related to the area under study;
- o_i represents an origin of the i-th zone (with $i = [1, \dots, n_i]$);
- d represents a destination of the area under study (with $d = [1, \dots, m]$);
- wd_{o_id} is the weighted distance from origin o_i to destination d;
- rel_d is the relative relevance of destination d calculated as the ratio between average number of daily tourists at d and the highest value of average number of tourists among all destinations m in the area under study;
- s is the corrective parameter for traffic light intersections;
- ntl_{o_id} is the number of traffic light intersections along the minimum path between the origin o_i and destination d;
- int_{o_id} is the number of intersections along the minimum path between origin o_i and destination d;
- bs_{o_i} is the average number of available shared bikes within a radius r with center in the origin o_i;
- bs_d is the average number of available shared bikes within a radius r with center in destination d;

- bs_{max} is the maximum quantity of shared bikes that may be present in a generic circular area with radius r.

Concerning the weighted distances, $wd_{o_i d}$, the length of each road link (l_a) is calculated with the follow expression:

$$l_a = \frac{dist_a}{\gamma_a}$$

where:

- $dist_a$ is the real road link distance;
- γ_a is a parameter greater than or equal to 1. It is equal to 1 if there are no cycle infrastructures on the road link and the greater than 1 it is, the safer the link is considered by users.

Finally, the minimum paths between o_i and d, required for the calculation of $wd_{o_i d}$, $ntl_{o_i d}$, and $int_{o_i d}$, are calculated on the network where the road links have distance l_a.

The BTI_i indicator assumes positive values. The higher the value of BTI_i the greater the bike friendliness. In fact, it increases with the presence of bike lanes, road intersections with traffic lights, the presence of bike-sharing systems and the proximity between accommodation and POIs. This value is related to a zone in the area under analysis and it can not be compared with the values of zones in other cities. It is only possible to compare zones located in the same area under study. Municipal councils may have an interest in improving tourist bike friendliness by increasing these values, especially in areas where the indicator values are low. [ruturn to index]

4.2. Application of BTI

In the case under analysis, we focused on the city center of Bari, which is the area most used by tourists.

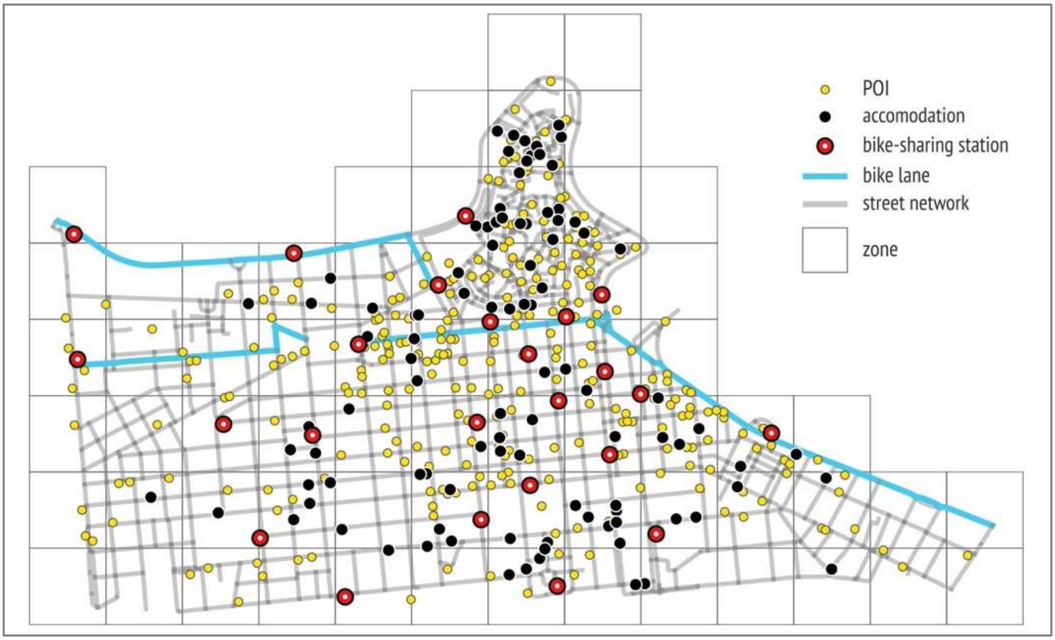


Figure 4 Map with input data.

In the area under analysis, there are 4 kilometers of bike lanes, 24 bike sharing stations, 110 accommodation facilities, and 292 POIs (Fig. 4). Data collection was conducted by author Fulvio Morgese. The entire area was divided into 66 zones with a square mesh grid zoning with sides of 250 meters. The other parameters of BTI_i have been set as below. It is necessary to explain the value of γ_a and s, which are not suggested in literature as we defined them and should be calibrated, for example through questionnaires. As a first approach, we fixed the values of these parameters as follows. As regards weighted distances, we considered that cyclists are willing to double the length of their route with the presence of a protected/segregated cycle lane (Deenihan and Caulfield, 2015). We took into consideration four types of bike lanes with relative γ_a values: protected bike lanes ($\gamma_a = 2$), buffered bike lanes ($\gamma_a = 1{,}8$), conventional bike lanes separated from motor vehicle travel lanes through a white lane line marking ($\gamma_a = 1{,}6$), and shared bike lanes, or "sharrows" ($\gamma_a = 1{,}4$). With these values we considered links with protected bike lanes more attractive to tourists than links without cycling infrastructures and links with "inappropriate" bike infrastructures.

As concerns factor s, we set a value equal to 0.5. In this case, BTI_i increases if the number of road intersections with traffic lights is greater than half of the total road intersections, both considering the minimum route distance. On the other hand, it decreases if the number of road intersections with traffic lights is less than half of the total number of intersections along the minimum route distance.

Concerning relevance, we considered four POI classes assuming average daily visitor numbers. Each class has values of 5,000, 1,000, 100 and 10 respectively, starting from the point with the greatest affluence, such as the church of St. Nicholas, to the points with fewer visitors, i.e. restaurants and bars.

With regard to bike-sharing systems, we considered a radius of 300 meters which represents user willingness to walk from origin to the nearest bike-sharing station (Kabra et al., 2019). Since the bike-sharing system has only recently been established, we do not currently have the available average number of bikes in radius r. For this reason, we took into consideration the number of bike-sharing parking slots in radius r. In this way it was possible to calculate the BTI_i for each zone i.

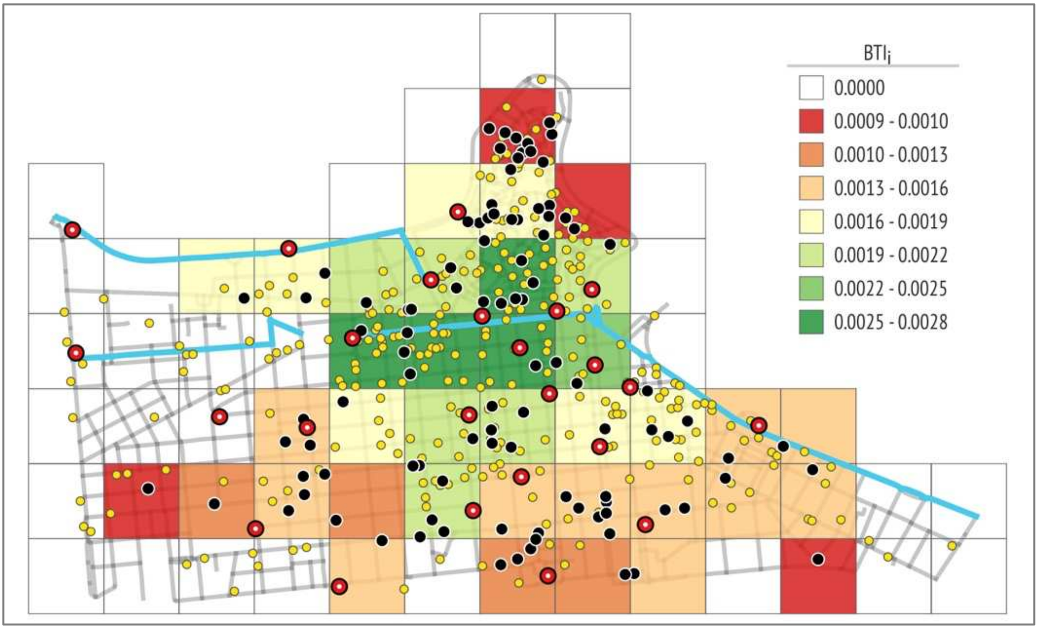


Figure 5 Map with BTIi values for the zones under consideration.

4.3. Results of Bike Tourism Indicator

The obtained values of the indicator are shown with a color scale from green to red (see Fig. 5). No color represents null value in zones without accommodation ($BTI_i = 0$). The color green represents the highest values of BTI_i (the best values), the color yellow represents medium values, and the color red represents the lowest values (the worst ones).

The central zones are green/yellow. This demonstrate that it is easier in these zones to move from accommodation to POIs because bike-friendliness is higher than in other zones of the area under study. This depends on the presence of cycling infrastructures and bike-sharing stations in the city center and near the most important POIs, for example those in the old town such as the church of St. Nicholas and other important locations. One way to improve this situation, for example, would be to increase the number of bike lanes and the number of bike-sharing stations even in the most remote zones of the city.

5. Multimodality trips of tourists

Micromobility provide intelligent, fast, and sustainable trips for tourist from accommodation facilities to attraction locations. However, some points of interest may be located away from the accommodation i.e. in a different city of a metropolitan area. In this case, cycling to the attractions may not be possible and multimodal bike and public transport trips can be considered for more sustainable tourism. Therefore, it is essential to identify how adequate a city transport infrastructures and services are for these types of trips. In this section, we propose a second cycling indicator of this thesis, for tourism accessibility with the aim of defining the level of multimodal bike-public transport friendliness through numerical values related to a specific zone in the main city of a metropolitan area. The indicator was applied to the metropolitan area of Bari (Italy) and results showed that the presence of bike lanes and bike-sharing plays an important role.

5.1. A Tourism Accessibility Indicator for Multimodal Bike-Public Transport Trips in a Metropolitan Area

This second indicator named Multimodal Bike and public transport Tourism Index, $MBTI_i$, related to a specific city zone i in the main city of the metropolitan area. $MBTI_i$ summarizes tourist multimodal bike-friendliness from all accommodation in the considered i-th zone, in the main city where the trip starts, to all the POIs outside the starting city and inside the metropolitan area under consideration. In other words, this indicator measures how convenient is for a cycle tourist to stay in an area of the main city and reach tourist attractions in the suburbs by leaving the hotel with a bike, depositing it in a rack near a public transport stop/station and taking public transport services to the suburbs.

The proposed indicator is based on the following factors:

- cycling infrastructures i.e., the presence of bike lanes and road intersections with and without traffic lights;
- presence of bike-sharing systems;
- presence of bike racks in the starting city;

- locations of the various accommodation facilities: hotels, B&Bs etc.;
- location of the suburban public transport stops/stations, which connect the main city with all the cities inside the metropolitan area under consideration,
- frequencies of the suburban public transport services;
- distances between accommodation and the location of suburban public transport stops/stations;
- number of POIs of the suburbs that can be reached by the suburban public transport.

The indicator is calculated with the following equation:

$$MBTI_i = \frac{\sum_{o_i=1}^{n_i} \sum_{d=1}^{m} \frac{1}{wd_{o_i d}} * \frac{nPOI_d}{tPOI} * af_d * \left(s + \frac{ntl_{o_i}d}{int_{o_i d}}\right)}{n_i}$$

where:

- n_i is the total amount of accommodation (origins) in a zone i;
- m is the total number of suburban public transport stops/stations (destinations) related to the main city of the metropolitan area (starting city) which have at least one bike rack or a bike share station within a radius r;
- o_i represents an accommodation (origin) of the i-th zone (with $i = [1, \ldots, n_i]$);
- d represents a suburban public transport stop/station of the starting city (with $d = [1, \ldots, m]$);
- $wd_{o_i d}$ is the weighted distance from origin o_i to destination d;
- $nPOI_d$ is the total number of the POIs connected with d, through the suburban public transport services;
- $tPOI$ is the total number of the POIs connected with the starting city, through the suburban public transport services;

- af_d is the average frequency related to d of the suburban public transport services;
- s is the corrective parameter for signalized intersections;
- ntl_{o_id} is the number of signalized intersections along the minimum path between the origin o_i and destination d;
- int_{o_id} is the number of intersections along the minimum path between origin o_i and destination d;

Concerning the weighted distances, wd_{o_id}, the length of each road link (l_a) is calculated with the following expression:

$$l_a = \frac{dist_a}{\gamma_a}$$

where:

- $dist_a$ is the real road link distance;
- γ_a is a parameter greater than or equal to 1. It is equal to 1 if there are no cycle infrastructures on the road link and the greater than 1 it is, the safer the link is considered by users.

Finally, the minimum paths between o_i and d, required for the definition of wd_{o_id}, ntl_{o_id}, and int_{o_id}, are calculated on the network where the road links have distance l_a.

The $MBTI_i$ indicator assumes positive values. The higher the value of $MBTI_i$ the greater the multimodal bike-friendliness. In fact, it increases with the presence of bike lanes, signalized intersections, the presence of bike-sharing systems, the proximity between accommodations and suburban public transport stops/stations, and the average of public transport frequencies at stops/stations. This value is related to a zone of the considered the main city of the metropolitan area and it can not be compared with the values of zones in other cities. It is only possible to compare zones located in the starting city. Metropolitan district councils may have an interest in improving tourist multimodal bike-friendliness by increasing these values, especially in areas where the indicator values are low.

5.2. The application of MBTI

The proposed indicator was applied to the metropolitan area of Bari (Italy).

The continuous flow of tourists throughout the year characterises the city of Bari, however the summer season is the most popular. In this context, given the large size of the metropolitan area and the limited presence of extra-urban cycle paths, for sustainable travel of cycle tourists it is also necessary to use suburban public transport services. In particular, for this application only suburban bus lines were considered given their greater coverage of the metropolitan area compared to local train lines. Most of the Bari accommodations are located in the city centre.

For this reason, the proposed indicator was only calculated for this area, which is characterized by 4 kilometers of bike lanes, 24 bike-sharing stations, 110 accommodation facilities, 12 suburban bus stops connected with 446 POIs of the considered metropolitan area suburbs. Data collection was conducted by author Fulvio Morgese.

The central area was divided into 64 zones with a square mesh grid zoning with sides of 250 meters (Figure 6, developed by the author Fulvio Morgese with software QGis).

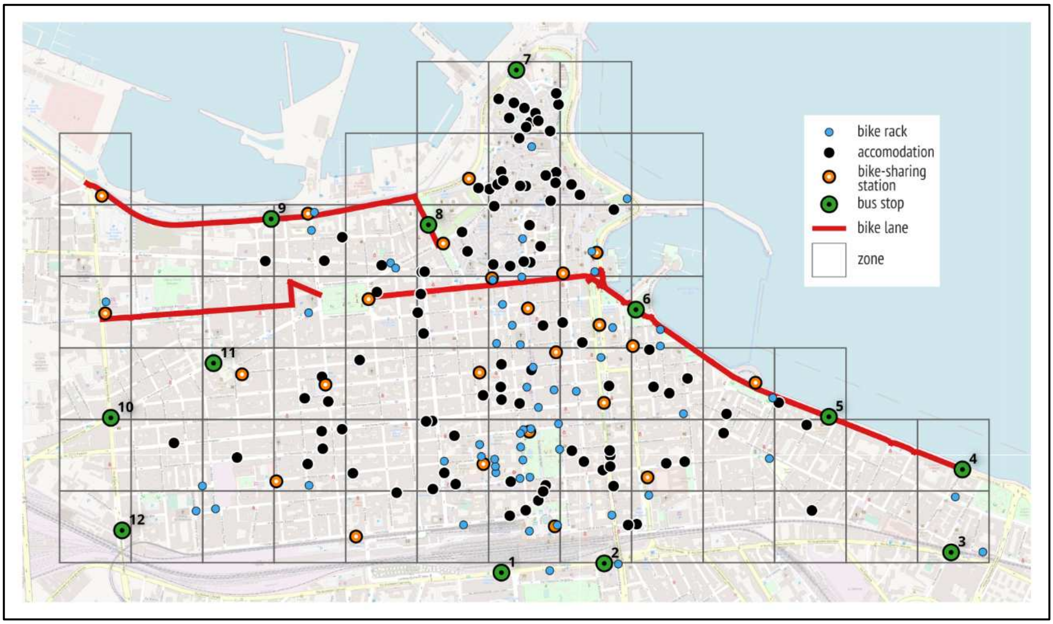


Figure 6 Bari city centre with input data (map data OpenStreetMap - openstreetmap.org/copyright).

Among the other parameters of $MBTI_i$, it is necessary to explain the value of γ_a and s, which are not suggested in literature as we defined them and should be calibrated, for example through questionnaires.

As a first approach, we fixed the values of these parameters as follows. As regards weighted distances, we considered that cyclists are willing to double the length of their route with the presence of a protected/segregated cycle lane, as we can see in the study of Deenihan and Caulfield (2015).

We took into consideration four types of bike lanes with relative γ_a values: protected bike lanes ($\gamma_a = 2$), buffered bike lanes ($\gamma_a = 1.8$), conventional bike lanes separated from motor vehicle travel lanes through a white lane line marking ($\gamma_a = 1.6$), and shared bike lanes, or “sharrows” ($\gamma_a = 1.4$).

With these values we considered links with protected bike lanes more attractive to tourists than links without cycling infrastructures and links with “inappropriate” bike infrastructures. As concerns factor s, we set a value equal to 0.5.

5.3. Results of Multimodal Bike-public transportation Tourism Indicator

In this case, $MBTI_i$ increases if the number of signalized intersections is greater than half of the total road intersections, both considering the minimum route distance. On the other hand, it decreases if the number of signalized intersections is less than half of the total number of intersections along the minimum route distance.

The parameter $nPOI_d$ is calculated by considering monuments and attractive places located in the suburban cities under consideration. Average bus frequencies, af_d, are calculated in an interval of time from 6 a.m. and 11 p.m.

With regard to racks and bike-sharing station systems, we consider available only the ones who are located in a radius r of 300 meters (Kabra et al., 2019) from bus stops.

Bike-sharing stations are considered only if there is another station into the same radius r from the starting accommodation point. In this way it was possible to calculate the $MBTI_i$ for each zone i. The obtained values of the indicator result of a calculation performed with MathLab software and shown with a colour scale from blue to red (see Figure 7, developed by the author Fulvio Morgese with software QGis).

No colour represents null value in zones without accommodation ($MBTI_i = 0$). The blue colour represents the highest values of $MBTI_i$ (the best values), the yellow colour represents medium values, and the red colour represents the lowest values (the worst ones).

Zones that had dark orange colour before, become light blue and yellow. For this reason, the addition of these new bike lanes makes an overall improvement in the context, in particular, the value of $MBTI_i$ indicator become higher in proximity of the planned bike lane represented in green.

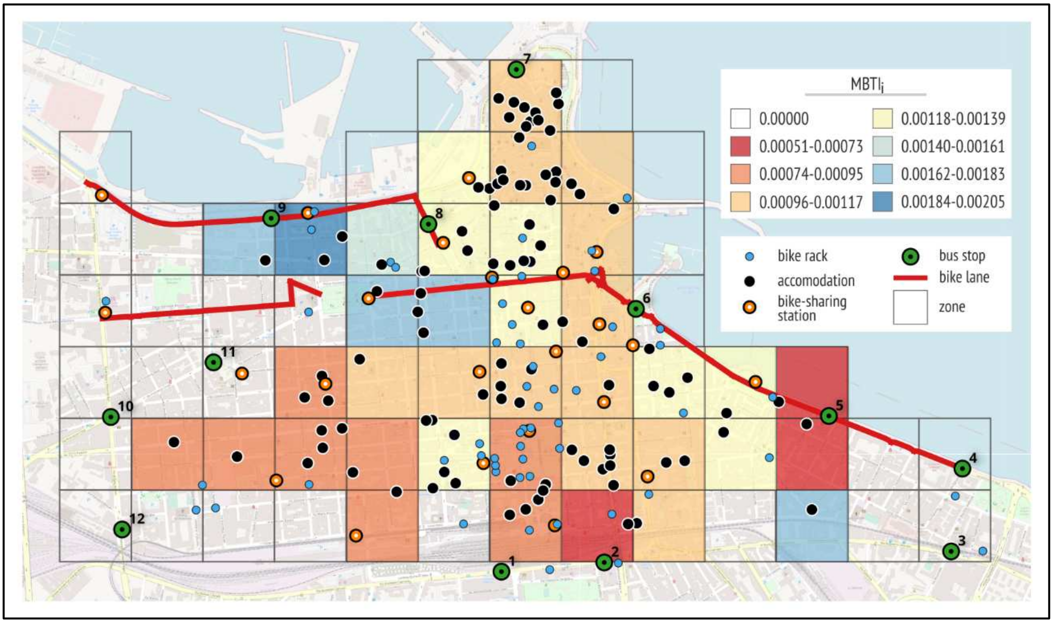


Figure 7 Map with MBTIi values for the zones under consideration (map data OpenStreetMap - openstreetmap.org/copyright).

6. Sustainable Tourism and Urban Resilience

Sustainable tourism is becoming increasingly important as shared micro-mobility systems allow users to cover short to medium distances independently and sustainably. Their use can be strategic during major events, because of their availability and capacity to avoid traffic. The use of shared micro-mobility systems can be strategic during large events due to their availability and ability to avoid traffic. On the other hand, at the same time, it is necessary to analyze the resilience of urban road networks for cycling tourism during and after major events. To address this aim, we propose a cycling resilience indicator for sustainable tourism in urban road networks to define road network resilience and the relevance of each network link. This is the third indicator in this work, one of the two resilience indicators in this thesis and was applied to the city of Bari (Italy) and the results proves to be of great interest for municipal councils.

During major events in urban areas, such as concerts in local squares, demonstrations, and sporting events, preventing the transit of vehicles along one or more road network links becomes necessary. In general, the closed links remain accessible on foot or to pedestrians walking with a bike, excluding some cases where the transit of pedestrians is also prohibited. For this reason, during major events, bike accessibility to the city Points of Interest (POIs), including the event location itself, may change. More or less significant variations in bike accessibility denote a lesser or greater urban transportation network resilience in terms of cycling, respectively. In this study, we intend to evaluate, through a new proposed indicator, how cycling tourism accessibility changes following the closure to traffic of one or more urban road links.

6.1. A Resilience Indicator for Sustainable Tourism in Urban Road Networks

This indicator named Resilience Bike Tourism Index (RBTI), measures how resilient the urban road network is with respect to closure of one or more links of the network during major events. This indicator is calculated by taking into consideration several cycling tourism accessibility factors such as the presence of cycle

lanes and road intersections with and without traffic lights, the presence of a bike sharing system and the locations of various accommodation facilities and POIs. The RBTI is calculated according to the following Eq. (1).

$$RBTI = \frac{\sum_{o=1}^{n}\frac{g_o}{max(\boldsymbol{G})}\sum_{d=1}^{m}\frac{1}{wd_{o,d}(J)}*rel_d*\left(s+\frac{ntl_{o,d}(J)}{int_{o,d}(J)}\right)*\left(1+\frac{\frac{bs_o(J)+bs_d(J)}{2}}{bs_{max}}\right)}{\sum_{o=1}^{n}\frac{g_o}{max(\boldsymbol{G})}\sum_{d=1}^{m}\frac{1}{wd_{o,d}(J_0)}*rel_d*\left(s+\frac{ntl_{o,d}(J_0)}{int_{o,d}(J_0)}\right)*\left(1+\frac{\frac{bs_o(J_0)+bs_d(J_0)}{2}}{bs_{max}}\right)} \quad \textbf{(1)}$$

where:

- $\boldsymbol{J}$ **is the urban network road link configuration during the major event;**
- $\boldsymbol{J}_0$ **is the urban network road link configuration with no major event;**
- n **is the total amount of accommodation (origins);**
- m **is the total number of POIs (destinations);**
- o **is an origin (with** $o = [1, 2, \ldots, n]$**);**
- d **represents a destination (with** $d = [1, 2, \ldots, m]$**);**
- g_o **is the total number of guests of the accommodation** o **during the major event;**
- $\boldsymbol{G}$ **is the vector of guests of all accommodation (with** $\boldsymbol{G} = [g_1, g_2, g_3, \ldots g_n]$**);**
- $wd_{o,d}$ **is the weighted distance from origin** o **to destination** d**;**
- rel_d **is the relative relevance of destination** d **calculated as the ratio between average number of daily tourists at** d **and the highest value of average number of tourists among all destinations** m**;**
- s **is the corrective parameter for traffic light intersections;**
- $ntl_{o,d}$ **is the number of traffic light intersections along the minimum path between the origin** o **and destination** d**;**
- $int_{o,d}$ **is the number of intersections along the minimum path between origin** o **and destination** d**;**

- bs_o is the average number of available shared bikes within a radius r with centre in the origin o;
- bs_d is the average number of available shared bikes within a radius r with centre in destination d;
- bs_{max} is the maximum quantity of shared bikes that may be present within a radius r.

Concerning the weighted distances, wd_{od}, the length of each road link (l_a) is calculated with the following expression:

$$l_a = \frac{dist_a}{\gamma_a} \qquad (2)$$

where:

- $dist_a$ is the real road link distance;
- γ_a is a parameter greater than or equal to 1. It is equal to 1 if there are no cycle infrastructures on the road link and the greater it is than 1, the safer the link is considered by users.

Finally, the minimum paths between o and d, required for the definition of wd_{od}, ntl_{od}, and int_{od}, are calculated on the network according to Eq. (2).

The proposed indicator represents the ratio between the weighted sum of cycling tourism accessibility from all accommodation to all POIs during the major event and when there are no closures of urban network links. In other words, Eq. (1) allows us to define road network resilience and the relevance of each network link or a group of them for cycling tourism. Based on its definition, $RBTI$ is a positive dimensionless number. The higher the value of $RBTI$, the greater the resilience. When the closure of one or more links reduces (or does not affect) cycling tourism accessibility, $RBTI$ is greater than zero and less (or equal) than 1. There may be cases in which the closure of one or more links may improve cycling tourism accessibility and *RBTI* takes on values greater than 1. For example, this happens for links that are normally one-way and which, once closed, become two-way for pedestrians walking with bikes. Another example could be the case where the

closure of a link leads to an increase in the number of signalized intersections along the new minimum path which prevails in the indicator on the increase in distance travelled. *RBTI* was applied to the city of Bari in the Apulia region (Italy) as described in the next section.

6.1.1. Application of RBTI

In the case under analysis, we focused on the city center of Bari, Figure 8(a) developed by the author Fulvio Morgese with software QGis, which is the area most visited by tourists. In this area, we identified 4 kilometers of current bicycle lanes (depicted in light blue), 24 bike-sharing stations, more than 100 accommodation facilities, and about 300 POIs. Data collection was conducted by author Fulvio Morgese. In the near future, the expansion of the current cycle path network is expected, with the addition of bike lanes depicted in green (current + P1 cycle path network) and subsequently of bike lanes showed in magenta (current + P1 + P2 cycle path network).

Figure 8(b), developed by the author Fulvio Morgese with software QGis, shows 3 typical scenarios involving city road link closures (depicted in brown), corresponding to three major events held in the city of Bari that is the patronal feast of Saint Nicholas, S1 (the event attracts hundreds of thousands of people to the central area of the city), a running race, S2, and a usual closure for musical concerts and political rallies, S3.

Figure 8 Bari city center map with input data; (b) Different scenarios analyzed.

The parameters of the $RBTI$ were set as follows. The values of γ_a, are not explicitly suggested in the literature therefore, as a first approach, we set their values considering that the presence of a protected or separated cycle lane would cause cyclists to be willing to double the length of their route (Deenihan et al., 2016) (Deenihan and Caulfield, 2015). Consequently, we assumed these γ_a values: protected bike lanes ($\gamma_a = 2$), buffered bike lanes ($\gamma_a = 1.8$), typical bike lanes divided from motor vehicle travel lanes by a white lane line marking ($\gamma_a = 1.6$), and shared bike lanes, or "sharrows" ($\gamma_a = 1.4$). Furthermore, γ_a is set equal to 0.8 for the closed links where is allowed to walk with a bike. This value is less than 1 because

it is assumed that a cyclist is less inclined to move if it is necessary to walk with the bike rather than ride the bike. Regarding factor s, we assume, as a first attempt (we find no suggestions for this value in the literature), a value of 0.5. In this way the minimum path distance increases if the percentage of traffic light intersections is more than half of all road intersections. It lowers, however, if the number of road intersections with traffic lights is less than half of the total number of intersections along the shortest route distance. In terms of POIs significance, we classified rel_d (the relative relevance of destination d) in four classes, based on the average number of visitors per day. Each class has a value of 5,000, 1,000, 100, and 10, ranging from the most visited site, such as the St. Nicholas Church, to the locations with the fewest tourists, such as restaurants and bars. It should be noted that, especially during major events, Bari city center hotels and other accommodations are almost full, so in the g_o calculation, instead of the number of guests, the number of beds was taken into account. Concerning the bike-sharing system, since it has only recently been implemented, we do not currently have the available average number of bikes in radius r. For this reason, we took into consideration the number of bike-sharing parking slots instead. In particular, we considered a radius of 300 meters which represents the majority of user willingness to walk from the origin to the nearest bike-sharing station (Kabra et al., 2019).

6.1.2. Result of Resilience Bike Tourism Indicator

As a first evaluation, we calculate our indicator for individual link closures and for each of the three configurations of the cycle path network, to provide municipalities with a general indication of the importance of a particular link in the context of cycling tourism and the overall resilience of the network as a function of an individual link closure. For each configuration, two cases were considered: closed links also to pedestrians *(RBTI closed)* and closed links accessible on foot or to pedestrians walking with a bike *(RBTI on foot)*. The obtained *RBTI closed*

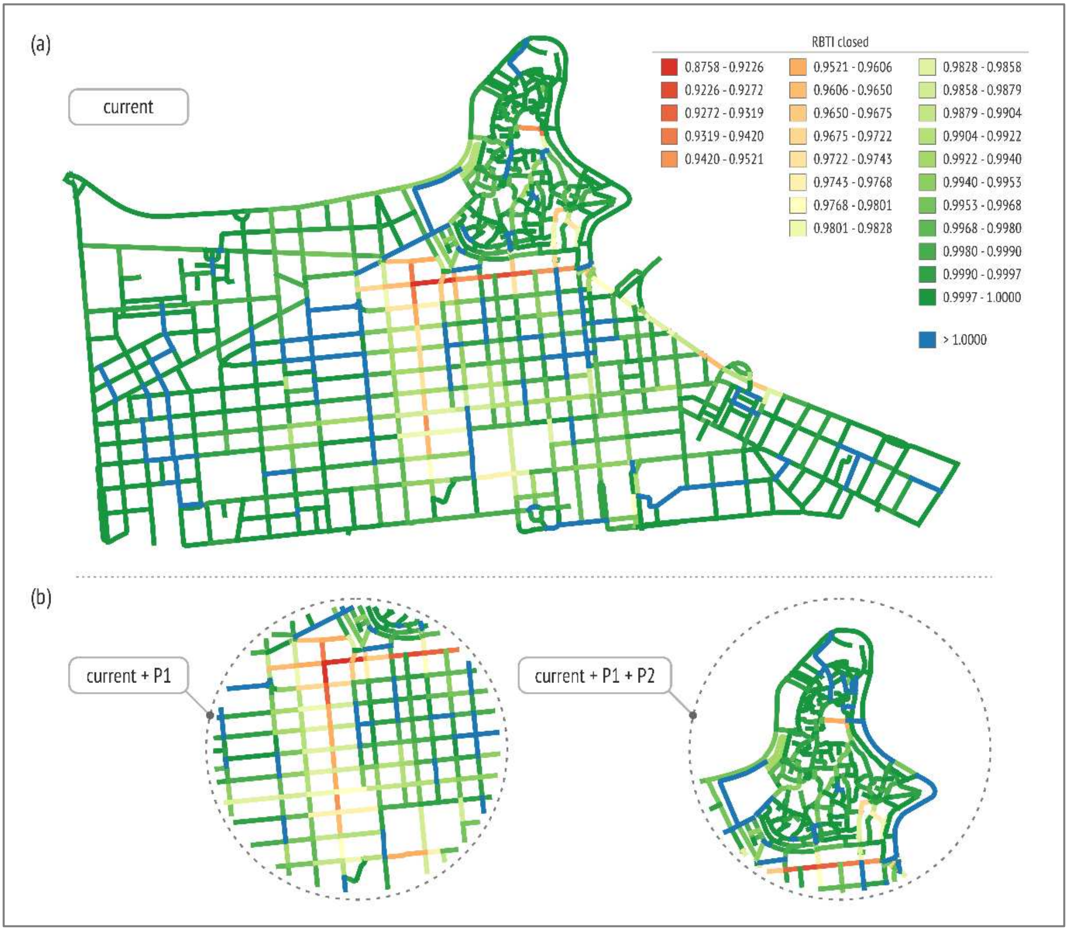


Figure 9 (a) RBTI closed values - current cycle path network; (b) RBTI closed values - current + P1 and current + P1 + P2 cycle path network.

values is the result of a calculation performed with MathLab software and shown in Figure 9, developed by the author Fulvio Morgese with software QGis.

RBTI closed values were depicted subdividing them according to Jenks natural breaks (Jenks, 1967) with a color scale that goes from red to green. The redder the color of each link is, the more its closure lowers the value of the *RBTI* ratio. Therefore, that link becomes very important for the resilience of the network, and it mustn't be closed, as its closure would lead to a significant reduction in resilience. Dark green indicates a value close to 1, so closing or opening the link does not change cycling tourism accessibility. Blue color indicates that closing the link increases the cycling tourism accessibility given that *RBTI* takes values greater than 1. Observing Figure 9(a), it is worth noting that, in general, the resilience of the *current* road network is quite high regardless of the closed link. In fact, the lowest value of the *RBTI closed* is 0.8758 that is, at most, a worsening of the cycling tourist accessibility of approximately 12% is obtained. The worst situations occur mainly in the central area and, in particular, along two important roads of the city. The addition of the P1 bike lanes to the network *(current + P1)*, shows a worsening of the indicator, right where, or around, the new cycle lanes was placed (see Figure 2(b)). However, adding more bike lanes (*current + P1 + P2* cycle path network), leads to an increase in resilience in the area of the P2 bike lanes. In fact, from the comparison between Figure 9(a) and the right excerpt of Figure 9(b), we can see the increase in the number of closed links with an indicator greater than 1.

In the second case *(RBTI on foot)* the indicator values improve in general (Figure 10, developed by the author Fulvio Morgese with software QGis). This is due to the possibility of passing anyway (walking with the bike) along a closed link.

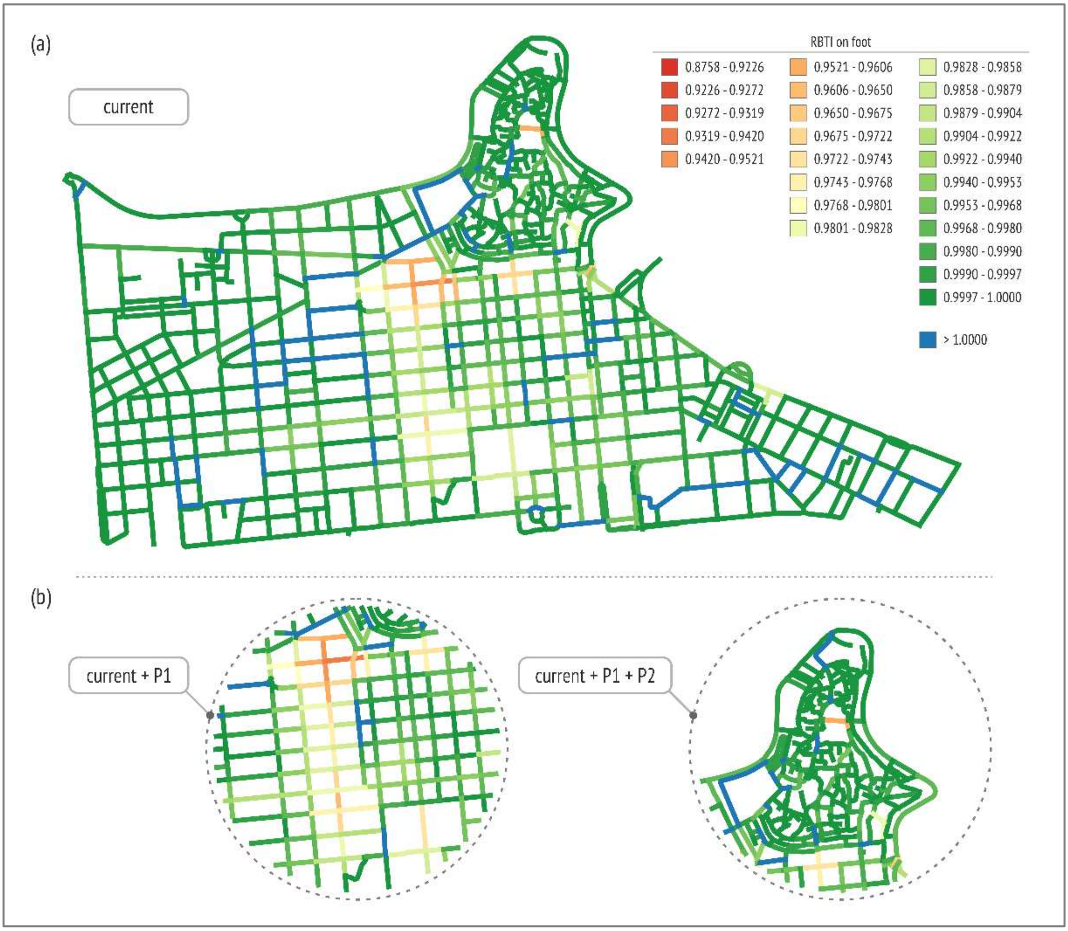


Figure 10 (a) RBTI on foot values - current cycle path network; (b) RBTI on foot values - current + P1 and current + P1 + P2 cycle path network.

Furthermore, one-way links, once closed, become two-way for pedestrian with a bike and this can lead to a reduction in minimum path distances.

Also in this case, the addition of P1 still worsens the indicator where bike lanes are added. The opposite occurs for the *current + P1 + P2* cycle path network, in which there is a reduction in resilience in the area of the P2 bike lanes (see Figure 10(b)). This happens because, unlike the previous case, it is still possible to pass along a closed link but with a greater weighted distance.

Finally, the indicator was applied for each case, each scenario (group of links) and for each of the three configurations of the cycle path network. The results obtained are reported in Table 6. The indicator values *on foot* are always better than those *closed*. It can be noted that the worst situations (the lowest values of the indicator) are recorded for scenario *S1*, the scenario with massive closures. For these combinations, cycling tourist accessibility is reduced by approximately 45% *(RBTI closed - current)*. Again, for scenario *S1*, this percentage improves a lot, reaching around 25% for the *RTBI on foot*. For *RBTI on foot* case, given the network characteristics, unlike the *RBTI closed* case, *S2* shows better values than *S3*, despite the greater number of closed links. The addition of new bike lanes always leads to an improvement in the resilience of the network, even if only in small quantities especially for scenario S2.

Table 6 Percentage of urban routes in km divided into macro-areas (%).

	Scenario	current	current+P1	curr+P1+P2
RBTI closed	S1	0.523	0.565	0.566
	S2	0.795	0.802	0.804
	S3	0.823	0.871	0.881
RBTI on foot	S1	0.755	0.775	0.777
	S2	0.934	0.938	0.940
	S3	0.907	0.928	0.934

6.2 Sustainable Cycle Tourism: An Efficiency Indicator for Assessing the Resilience Of Transportation Networks In Urban Areas

Sustainable tourism development relies on the resilient assessment and management of human flows, particularly within urban environments. To ensure urban safety and resilience, it is essential to evaluate emerging modes of transport for sustainable tourism with regard to both the design and transformation of urban spaces, as well as the organization of the ecosystem relationships that sustain these infrastructures. Overtourism represents a major threat to environmental sustainability, making its mitigation a critical objective for urban planners and policymakers.

In this study, we employ the input-oriented CCR Data Envelopment Analysis (CCR-DEA) method to assess the sustainability of transport mode choices for cycle tourism. This robust analytical framework evaluates the relative efficiency of decision-making units (DMUs) by comparing input resources, such as infrastructure investments, with output performance indicators like accessibility, resilience, and user satisfaction. CCR-DEA is particularly suited to addressing the complexity of multidimensional challenges, as it identifies best practices and highlights inefficiencies within the system.

Our case study focuses on the city of Bari, a coastal city experiencing a significant surge in tourism, which underscores the need to manage increasing pressures on urban mobility networks. The methodology integrates quantitative performance analysis with a resilience-oriented framework, enabling the identification of critical vulnerabilities in the cycle tourism infrastructure. To this end, we propose an efficiency-based indicator that quantifies urban resilience specific to cycle tourism environments. This indicator serves as a foundational tool for municipalities and public authorities, offering actionable insights for planning and decision-making processes aimed at fostering sustainable, adaptable, and inclusive urban mobility solutions.This section introduces the mathematical formalization of the last proposed indicator in followed section by the input-oriented CCR-DEA model description with selected input and output in Section 5.2.1.

In this study, we introduce a novel specific indicator, named Efficiency Cycle Tourism Indicator (ECTI), in order to evaluate road network resilience for cycle tourism in urban areas. The proposed Efficiency Cycle Tourism Indicator (ECTI) is formalized by Eq. (1) as follows:

$$ECTI_j = \sum_{a=1}^{n} \partial_a \sum_{p=1}^{m} d_{ap} \cdot rel_p \cdot S_{ap} \cdot B_{ap} \quad (1)$$

where:

- a is the origin accommodation (origin);
- n is the total number of accommodation (origins);
- ∂_a is the relevance of accommodation a;
- p is the destination of the POI in the study area, where $p \in \{1, \dots, m\}$;
- m is the total number of POIs (destinations) within the study area;
- d_{ap} is the inverse of the weighted distance from origin a to destination p;
- rel_p is the relative relevance of destination p calculated as the ratio between the average number of daily tourists at d and the highest value of the average number of tourists among all destinations m in the study area;
- S_{ap} is the relative ratio of road intersections with traffic lights;
- B_{ap} is the indicator of available shared bikes within a radius r.
- j is the road link (or the group of links) that is closed or disrupted. Thus, $j \in \{1, \dots, L\}$ where L is the maximum number of road links (or group of links) of the transport network within the study area;

Specifically, each term of Eq. (1) is formulated as follows:

The relevance of accommodation ∂_a is expressed by Eq. (2):

$$\partial_a = \frac{bed_a}{\max(\boldsymbol{BED})} \quad (2)$$

where:

- bed_a is the total number of beds in the city's accommodation (hotel, B&B, etc.);
- $\max(BED)$ is the maximum number of beds among all accommodations in the study area;
- $\boldsymbol{BED}$ is the vector of the number of beds of all accommodations in the study area.

The inverse of the weighted distance d_{ap} from origin a to destination p is expressed by Eq. (3):

$$d_{ap} = \frac{\gamma_a}{dist_a} \tag{3}$$

where:

- $dist_a$ is the real road link distance;
- γ_a is a parameter greater than or equal to 1. It is equal to 1 if there is no cycle infrastructure on the road link j, and the greater the value, the safer the link is perceived to be by cyclists.

The relative ratio of road intersections equipped with traffic lights is expressed by Eq. (4):

$$S_{ap} = s + \frac{sig_{ap}}{int_{ap}} \tag{4}$$

where:

- s is the corrective parameter for road intersections with traffic lights;
- sig_{ap} is the number of traffic light intersections along the minimum path between origin a and destination p;
- int_{ap} is the number of road intersections along the minimum path between origin a and destination p;

Finally, the value of available shared bikes B_{ap} within the radius r is formulated by Eq. (5):

$$B_{ap} = 1 + \frac{\frac{bs_a + bs_p}{2}}{bs_{max}} \tag{5}$$

where:

- bs_a is the average number of available shared bikes within the radius r with center in the origin a
- bs_p is the average number of available shared bikes within the radius r with center in destination p;
- bs_{max} is the maximum quantity of shared bikes that may be present in a generic circular area with radius r.

The proposed $ECTI_j$ indicator is calculated for each closed road link j through the input-oriented CCR-DEA, as described in Section 5.2.1.

6.2.1. The input-oriented CCR-DEA model

One of the most popular mathematical models for evaluating and measuring the efficiency of a system is the DEA model, which is used to calculate the relative effectiveness of Decision-Making Units (DMUs). In this section, we applied the well-known input-oriented CCR-DEA model (Charnes et al., 1994, 1978).

We set as the output of the input-oriented CCR-DEA model the specific indicator $ECTI_j$ with a range of values between 0 and 1. The higher the value of the $ECTI_j$ indicator, the more efficient is the road link j affected by a disruption (e.g., road maintenance works, traffic accidents, events, etc.) for cyclists.

Concerning the DMUs, we set the closed road link j (or group of road links) as a single DMU. So that, the specific indicator $ECTI_j$ is calculated only when the corresponding road link j (or group of links) is closed. In other words, we are evaluating the efficiency of each road link j affected by disruption with respect to all other road links non-affected by disruption. Before introducing inputs, we calculated all shortest paths from accommodations a (origins) to POIs p (destinations) assuming that these routes represent the cyclists' path choices. We set three inputs in the proposed model, listed as follows:

- Input 1: The number of times the road link j falls within all shortest paths between accommodations a and POIs p. The higher the number, the higher the relevance (resources) of the road link j for cyclists in the study area.

- **Input 2: The sum of the relative ratios of traffic light intersections S_{ap} along all shortest paths between accommodations a and POIs p where the road link j is included. The higher the value, the higher the relevance (resources) of the road link j to achieve high output values.**
- **Input 3: The sum of available shared bikes B_{ap} along all shortest paths between accommodations a and POIs p where the road link j is included. The higher the number, the higher the relevance (resources) of the road link j for cyclists in the study area.**

In practice, each road link j, set as DMU, is the sum of the three inputs. If the DMU has a high value (high resources) it means that the closure of the road link j will result in a high value of the output $ECTI_j$. Therefore, the road link j is efficient with high bikeability.

An important aspect of the proposed model is the relation between road link efficiency $ECTI_j$ and road network resilience for cyclists. We assume that the high efficiency of road link j can be seen as a high resilience of the road network if it is closed. In other words, the road network reflects resilience to the closure of the road link j. This raises the question: is it possible to close the road link j while maintaining a well-functioning cycling network? If so, we would expect $ECTI_j$ values close to 1. Conversely, if the closure of the road link j significantly decrease cycling network performance, we would expect $ECTI_j$ values close to 0. Therefore, we can evaluate the relevance of each road link j of the study area, and this can be seen as a guideline for decision-makers or public authorities against its closure during scheduled events.

It is possible to observe different cases according to the combination of input values, output values, and road network resilience.

Let us consider a scenario with low input values (resources) of a road link j. If the output $ECTI_j$ obtained from input-oriented CCR-DEA returns a high value despite the closure, the corresponding road link j is even more efficient than the previous case. Thus, the resilience of the road network to road link j closure will be even greater and represents the best-case scenario. Conversely, if road link j has

high input values but obtains a low output value the resilience of the road network due to its closure will be low. This represents the worst-case scenario. Finally, two intermediate scenarios occur considering medium input and output values.

In detail, we identify six scenarios according to the input and output values related to a road link j closure with different resilience levels of a road network:

- Maximum resilience occurs when very low input values generate very high output values;
- High resilience occurs when high input values generate high output values;
- Medium-high resilience occurs when medium-low input values generate medium-high output values;
- Medium-low resilience occurs when low input values generate low output values;
- Low resilience occurs when medium-high input values generate medium-low output values;
- Minimum resilience occurs when very high input values generate very low output values.

In conclusion, we assumed that the resilience of a road network can be conceptualized as the Efficiency Cycle Tourism Indicator $ECTI_j$, with a range from 0 to 1.

6.2.2. *Application of ECTI*

The input settings for the Efficiency Cycle Tourism Indicator (ECTI) calculation on the entire network was divided into 1,283 road links j, all of which were considered in this analysis, as shown in Figure 11 (developed by the author Fulvio Morgese with software QGis). In this area are identified 4 kilometers of cycle lanes, 24 bike-sharing stations, 110 accommodation facilities (Hotels, B&Bs, etc.), and 292 POIs. Data collection was conducted by author Fulvio Morgese. It is worth noting that the values of γ_a and s are not well-defined in the literature and, therefore, require a questionnaire to be defined and calibrated. Thus, we set these parameters to the following values: regarding weighted lengths, we consider that the presence of a protected or separated cycle lane encourages cyclists to be willing to double the length of their route (Deenihan and Caulfield, 2015). We have identified four types of cycle lanes, with corresponding γ_a values that vary according to their characteristics. These values range from a maximum of $\gamma_a = 2$ for protected cycle lanes to a minimum of $\gamma_a = 1.4$ for unprotected and promiscuous cycle lanes. Cycle lanes were weighted because γ_a modifies the distance based on the presence of cycle lanes, effectively weighting the distance.

Concerning the parameters s, we set $s = 0.5$. In this context, ECTI increases when the number of road intersections with traffic lights exceeds half of the total number of road intersections along the shortest path. Conversely, ECTI decreases if the number of intersections with traffic lights is less than half the total road intersections along the shortest path distance. Finally, we set parameter $r = 300$ meters as the willingness to walk by users from the accommodation (origin) to the nearest bike-sharing station (Kabra et al., 2019).

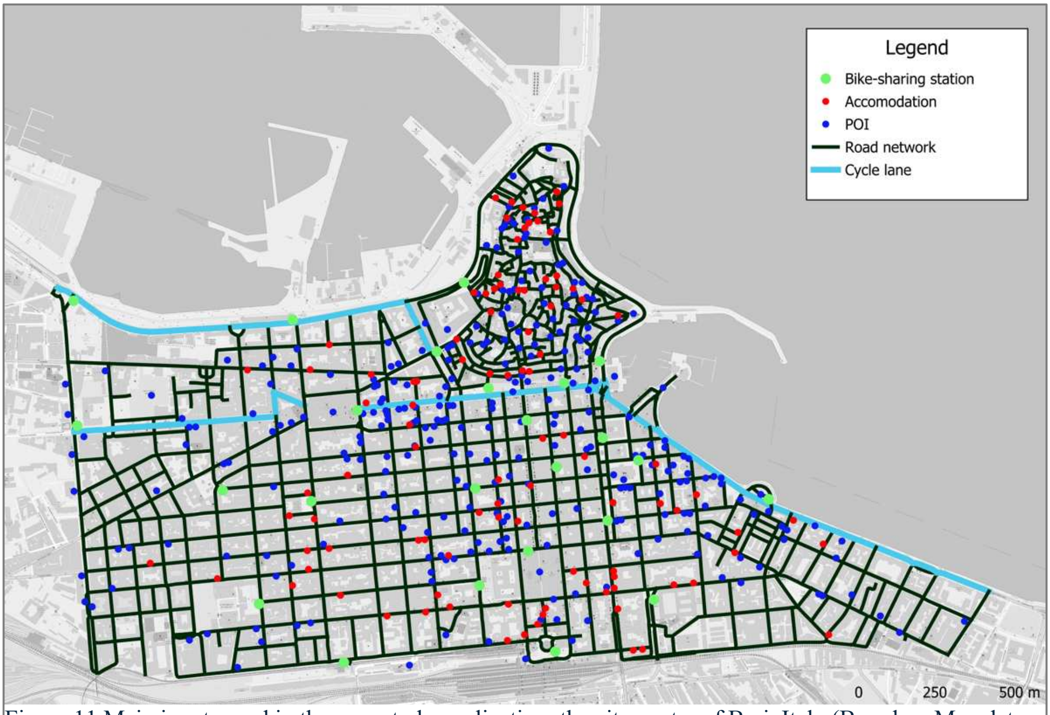


Figure 11 Main inputs used in the case study application: the city center of Bari, Italy (Based on Map data: ©OpenStreetMap contributors).

6.2.3. Result of Efficiency Cycle Tourism Indicator

The proposed model has been run with a 13th Gen Intel(R) Core (TM) i9-13950HX CPU (5.5GHz) and 64GB of RAM, coded in Matlab R2023b, and applied to the case study of Bari, Italy. The application results in terms of $ECTI$ for each road link j is depicted in Figure 12. In detail, as reported in the legend, the $ECTI$ values

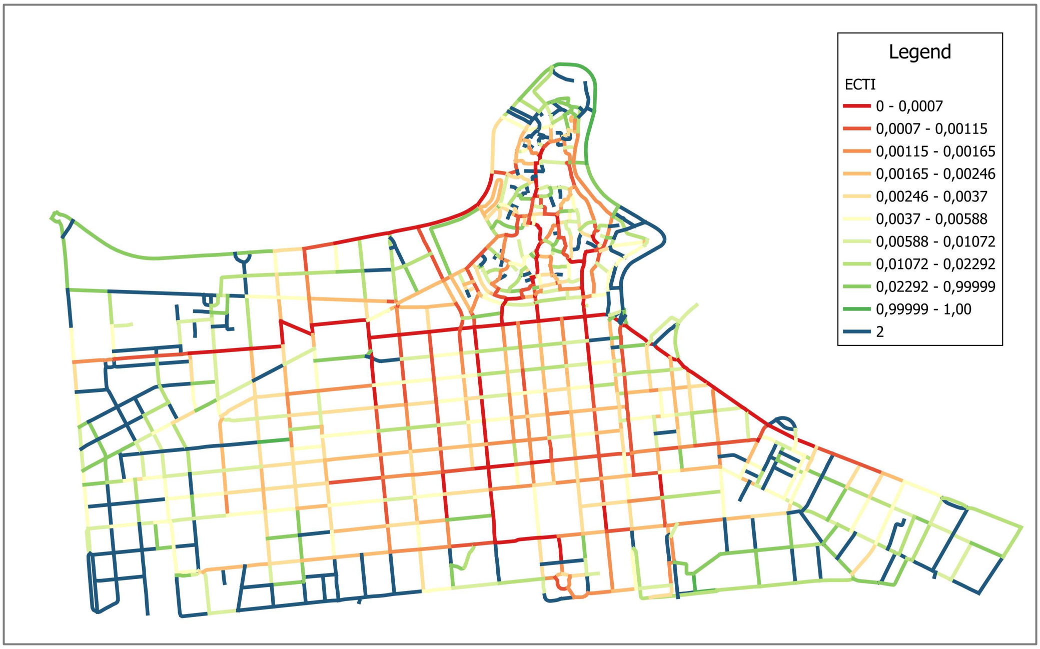


Figure 12 CTI results obtained in the case study application: the city center of Bari, Italy.

vary with small values close to 0 and gradually increase to values close to 1. The classification criteria used were quantiles, which better represent small variations in values by identifying ten groups (deciles) between 0 and 1 values.

In addition, we can see in Figure 12 (developed by the author Fulvio Morgese with software QGis) the presence of road links with blue color and with $ECTI$ value equal to 2. These road links have been set equal to 2 because they have never been selected from all shortest paths between origins (accommodations) and destinations (POIs). In other words, the closure of these road links does not affect the resilience of the road network and they were considered the most efficient, i.e., $ECTI = 1$. The reason we distinguished road links with $ECTI = 2$ is to avoid including them in the model due to null inputs while at the same time individuating them as the best candidates for the closure decision. Moreover, the road links marked in red color, i.e., $ECTI$ close to zero values, represent the worst case as closing them would severely affect the network's cyclability.

Let us consider the closure of road link groups rather than individual links. To address the issue of how the road network is affected and which groups of road links improve its resilience, we applied the K-means algorithm (Macqueen, 1967) to individuate six clusters of road link groups. Specifically, we divided the road network into 10, 20, 30, 40, 50, and 60 road link groups, as shown in Figure 13 (developed by the author Fulvio Morgese with software QGis).

This approach can assist municipalities in evaluating the implications of closing specific groups of road links and the subsequent changes within the road network resilience.

In the cluster 10 scenario (Figure 13a), the closure of this group represents the most resilient option for the network, causing the least damage compared to the other groups. The historical center of the city of Bari is identified as the least resilient area since the majority of POIs are located there, making it the most exposed to negative impacts. This observation is further illustrated by comparing Figure 13, where the green clusters correspond to a greater presence of blue road links in outlying areas, which do not significantly affect the road network resilience upon closure. As the number of clusters increases, we notice that the most critical area moves toward the center, and approaching the periphery shows an increase in efficiency. In addition, in the cluster 60 scenario (Figure 13f), we also notice a blue cluster identifying the group of roads that do not affect network resilience for cycle tourists.

In this work, the proposed model has some limitations that need to be acknowledged before a comprehensive evaluation of the results. A major drawback is the limited number of inputs considered, which may overlook other factors that influence the resilience of the system for cycle tourism. Moreover, the model requires updated data, such as the addition or removal of cycle lanes, accommodations, POIs, bike-sharing stations, etc.

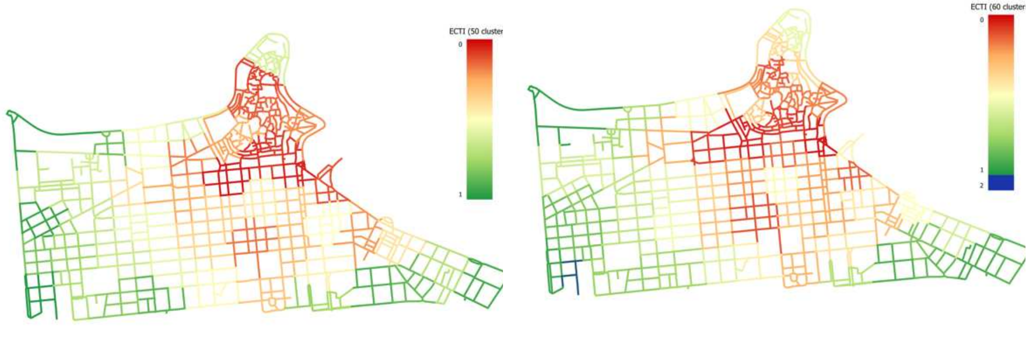
The proposed model used a first-degree polynomial with the input-oriented CCR-DEA model, which provides a linear and simplified representation of the observed results. However, this simplification may not capture all the complexities of a real-world bike-sharing system. Moreover, the most critical limitation of our approach is the quantity and quality of available data: increasing the amount of data can significantly improve the model's outcomes.

(a)

(b)

(c)

(d)



(e) (f)

Figure 13 ECTI results obtained with the K-mean clustering method in the case study application: the city center of Bari, Italy: (a) 10 clusters; (b) 20 clusters; (c) 30 clusters; (d) 40 clusters; (e) 50 clusters; (f) 60 clusters.

Road intersections between cycle lanes have been shown to have an impact on road network resilience. Finally, the inclusion of additional variables such as traffic flow, cycle demand, and buffer zones between stations could improve the accuracy of the model and a better evaluation of road network resilience.

CONCLUSIONS

In conclusion, the analysis highlights the pivotal role of the tourism sector in shaping the social, economic, and cultural perception of cities, as well as how micro-mobility, particularly cycling, can significantly contribute to sustainable transportation between accommodations and tourist attractions. Assessing the level of cycling infrastructure in cities is crucial for fostering sustainable tourism, with a focus on factors such as safe infrastructure and public transportation services, including bike-sharing systems.

This research has focused on developing and applying innovative indicators to evaluate cycling accessibility and urban resilience in a tourism context, with specific reference to the case study of Bari. The choice of Bari was deliberate: the city represents a significant example of the challenges and opportunities that characterize urban areas in southern Italy, where the potential for cycle tourism and sustainable mobility remains largely untapped. This socio-cultural and geographical context has made it possible to highlight unique and specific aspects that distinguish Bari from other cities, while also offering insights transferable to similar contexts at both national and international levels. Bari, with its rich history, culture, and strategic geographic location, serves as an ideal laboratory for analyzing the interplay between cycling mobility and sustainable tourism. The city is situated in a region where traditional modes of mobility struggle to meet the needs of growing tourist demand, while cycling infrastructure is still underdeveloped. The indicators proposed in this thesis, applied to the urban and metropolitan context of Bari, have identified critical areas requiring infrastructure enhancement and have offered targeted solutions. Moreover, the increasing interest in cycle tourism and other forms of experiential and slow tourism underscores the need for greater awareness among public authorities in the decision-making process. In this context, cycling mobility emerges as a catalyst for resilient and sustainable tourism development, underscoring the significance of addressing such a relevant topic in a southern Italian setting, which has often been overlooked in academic research. This approach not only lays the groundwork for improving local infrastructure but also provides valuable and replicable insights for other regions with similar characteristics.

The first contribution, an analysis of cycle tourism services in Puglia, points out the importance of cycle tourism as a key solution for the sustainable and resilient development of cities. Besides promoting physical activity and reducing carbon emissions, cycling addresses urban challenges such as congestion, pollution and climate change. The region of Puglia, in particular, can improve its resilience to external shocks and generate new economic opportunities and social inclusion through cycle tourism. The study highlights the growing interest of tourists in cycling, as evidenced by the popularity of routes in the Puglia Destination Bike. However, challenges emerge related to the poor adoption of planning tools and the lack of adequate infrastructure, such as accommodation and bike-friendly stations. To strengthen cycle tourism, authorities need to prioritise the improvement of cycling facilities, the promotion of sustainable mobility and the use of digital platforms to promote destinations. By exploiting the region's cultural and natural heritage, Puglia can consolidate its role as a top tourist destination.

The first indicator underlines the importance of cycling to improve the tourist accessibility of cities, especially small ones. An indicator is proposed to assess the bike-friendliness of a city, useful for designing cycling infrastructure and also applicable to other micro-mobility systems, such as electric scooters. The indicator, applied to the city of Bari, classifies areas according to their level of cycle accessibility, with a colour map highlighting the most bike-friendly areas (in green) and the least bike-friendly areas (in red). The model considers safety factors such as traffic light intersections and cycling infrastructure but can be improved by adding variables such as the number of accidents involving bicycles. It will be necessary to further calibrate the parameters and include this new data in future research. The indicator can also be used to design bicycle networks, improve tourism infrastructure and identify optimal locations for accommodation. An optimisation model under development aims to maximise the values of the indicator by considering cycling infrastructure as a variable.

The second indicator of tourist accessibility for multimodal travel, combining cycling and public transport in metropolitan areas. This indicator assesses the level of 'bike-friendliness' of an area in relation to the availability of cycling infrastructure and public transport, as in the case of the city of Bari. The resulting map highlights areas with greater or lesser ease of combining cycling and public transport for tourists. This indicator considers factors such as cycle lanes and safety (e.g. traffic light intersections), but can be improved by including additional variables, such as the number of cycling accidents. In the future, further parameter adjustments and the addition of variables will be necessary for greater accuracy. The indicator can be used to plan cycling networks, new public transport stops or change bus frequencies, with the aim of increasing the level of bike-friendliness. It can also help identify optimal locations for tourist accommodation and cycling infrastructure.

Two other indicators measuring the resilience of cycling-oriented urban road networks were also presented in this thesis, with a focus on major events that may lead to road closures. This indicator considers various factors, such as cycling infrastructure, traffic light junctions, bike-sharing systems and proximity to accommodation facilities and tourist attractions. The aim is to help administrations make decisions on which roads to close during events, minimising the impact on cycle tourism and promoting sustainable tourism. The case study of Bari demonstrates the complexity in determining the most appropriate closures. The indicator can also assess how infrastructure changes affect the resilience of the cycling network. In the future, it is planned to refine the indicator through questionnaires and to include multimodal trips, such as combining bicycles and public transport. Furthermore, an optimisation problem could be developed to design urban closures during events, respecting minimum resilience thresholds.

The last contribution aims to assess the urban resilience of a road network in the context of cycle tourism by determining the network's ability to overcome disruptions along the way. With the growth of cycle tourism in large tourist cities, a well-organised road network with adequate infrastructure is crucial for developing

sustainable mobility. To address this issue, a specific indicator was developed, called the Efficiency Cycle Tourism Indicator (ECTI), which measures the efficiency of road connections in case of closures due to events or works. The indicator was applied using a Data Envelopment Analysis (DEA) model to assess the impact of closures on the road network, considering three main inputs: frequency of connections on minimum routes, presence of traffic lights and availability of bike-sharing stations. The model was tested in the centre of Bari, Italy, showing that the most efficient connections are in the peripheral areas, while the most critical ones are near the historical area. The model can also be extended to users of electric scooters and other micro-mobility solutions. Future improvements include the integration of a multimodal index that considers other sustainable transport modes, such as walking and public transport, and the expansion of the study area to include suburban contexts.

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CURRICULUM

Management Engineer and PhD student in Environmental, Territorial and Building Risk And Development at Bari Polytechnic. In 2024 he won the Best Paper Award sponsored by Trivector Traffic in the field of innovation and sustainability at the international conference EWGT24 at Lund University. He is first author of 5 scientific publications, result of the activities developed in WP2 of the Spoke 8 of MOST - National Centre for Sustainable Mobility, funded by the European Union Next-GenerationEU (PNRR - Mission 4 Component 2, Investment 1.4). In 2023 he completes the advanced training course 'Expert Promoter of Cycling Mobility' at the University of Verona and in that year he is appointed member of the network of municipalities 'Pedalare per Viaggiare' coordination of ANCI Puglia, as an expert on the subject. In 2022 he qualified as an Industrial Engineer (section A) at the Order of Engineers of the Province of Bari. In the same year he obtained a 1st level MASTER'S degree in 'Models and Methods Of Industrial Transition' at the Polytechnic of Bari. In 2021 he graduated from the Polytechnic of Bari in Management Engineering with a specialisation in 'Entrepreneurship and Innovation' with a mark of 107/110 and discussing his thesis entitled: "The SELE-CALORE WATERWAY, from the great engineering work to the opportunities for development and sustainable tourism", which is currently being realised with PNRR funds. immediately afterwards he cooperates with ASSET - Apulia Region for the identification, design of cycle routes and the creation of excursion infrastructures, with which he produces the 'Puglia Bike Destination' cycle tourism guide. In 2018, he founded the 'ASD Bari Motivation Bike' with the aim of promoting the use of bicycles in all their forms. He is involved in activities to develop sustainable mobility and cycle tourism with the aim of improving society through the use of bicycles. His favourite quote is by Sergio Zavoli: 'The bicycle is a way of tuning life with time and space, it is going and staying within measures that are still human'.