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# A methodological perspective on understanding overtourism in Mediterranean Islands. The case of Sardinia region, Italy

Ginevra Balletto[1*], Mara Ladu[1], Silvia Battino[2] and Maria Attard[3]

**Abstract**
The term overtourism has become very popular, however it remains open to several interpretations. Its popularity is due to the acceleration and changes in tourism supply through the growth of tourist accommodation, low-cost airlines and other transport services, infrastructure and intermediary sectors, and demand that is driven by the growth in the world's population, the ageing of parts of the population, and the appearance of increasingly diverse households, that have occurred across the world, but especially in urban areas. In some contexts, such as those of Mediterranean islands, overtourism occurs mainly in short periods, with significant peaks in some months of the year (especially in summer), increasing the pressure on the natural and human environments and on the supply of services for local communities. This study proposes a place-based methodology to evaluate the spatial distribution and autocorrelation of a set of tourism indicators to understand the potential for overtourism in insular, island contexts using Geographic Information Systems (GIS) and Local Indicators of Spatial Association (LISA) maps. Validation of this methodology is conducted in the Sardinian region of Italy, which represents a relevant case study among Mediterranean islands. Results show how overtourism is concentrated in time and space, mainly affecting the summer season and clustering around coastal destinations. This approach aims to support policies that promote more sustainable tourism by improving the temporal and spatial distribution of tourist flows.

**Keywords** Overtourism, Spatial analysis, Mediterranean islands, Sardinia

## Introduction

Since the second half of the 20th century, tourism became a leading sector in the global economy, evolving from an activity which the few elites would engage in from time to time, to a mass phenomenon practiced by most. This affects all territorial scales, from the global to the local, and occurs when travelers/tourists perceive places as possible destinations for 'interaction', offering different experiences to everyday life. According to the World Tourism Organization (UNWTO), it is estimated that in 2023 1,286 million tourists traveled in search of 'the other and the elsewhere' with a preference for the European Continent (520 million arrivals). In this context, tourism is constantly evolving and is driven by the Continent's significant tangible and intangible heritage. Tourism and territory come together through a dialogue based on spatial relations and on the ability of the various actors to transform the landscape into a competitive product.

*Correspondence:
Ginevra Balletto
balletto@unica.it
[1]University of Cagliari, Cagliari, Italy
[2]University of Sassari, Sassari, Italy
[3]University of Malta, Imsida, Malta

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Therefore, the strategic role of tourism is to create 'new and diversified' economic and social value, thereby improving the quality of life for both host and guest communities (Britton 1991). The economic benefits, such as employment growth and new income generation, are certainly a positive contribution to the destination's balance of payments. However, if tourism is not well planned and programmed, it can give rise to negative externalities that can irreversibly affect the environmental and social balance of a place. According to economic theory, negative externalities lead to market failure and the most common in the tourism sector are the over-exploitation of resources, pollution, congestion, rising living costs, and the conflicting feelings between residents and tourists (Rinaldi 2011).

The extensive academic debate on managing the negative impacts of tourism dates to the mid-1960s and has intensified over time, leading to various schools of thought related to the concept of sustainability. In recent decades, the paradigm of sustainable tourism has prompted many stakeholders to consider growth and development choices for destinations that help to avoid exceeding the territory's carrying capacity. While sustainability theory has taken concrete form through strategies and projects promoting balanced environmental, economic and social development, the continuous and constant growth in tourism numbers has led to the emergence of new concerns about the future well-being of resident communities and visitors in tourist destinations (Koens et al. 2018; Mihalic 2020). Places become saturated and, as Simancas Cruz and González Medina (2024, p. 224) argue, tourists do not feel comfortable (psychological carrying capacity), the infrastructure becomes congested (physical carrying capacity), the quality of the environment deteriorates (environmental carrying capacity), there is a perception of excessive tourist development (perceptual carrying capacity), and residents begin to reject tourists (social carrying capacity). This results in a loss of the destination's attractiveness and competitiveness (economic carrying capacity).

Since 2016, these different spheres of carrying capacity have received 'new' attention, mainly from the media which has popularized the term 'overtourism'. Associated terms such as tourism-phobia (Blanco-Romero et al. 2019) and anti-tourism (Screti 2021) are thus feeding the media and academic worlds, which are working to identify and define the characteristics and boundaries of this 'new' phenomenon. The term overtourism is open to several interpretations and its popularity is due to accelerating changes in tourism supply (the growth of accommodation, transport especially of low-cost airlines, infrastructure and intermediary sectors) and demand (the growth of the world's population, the ageing of the population, and the appearance of increasingly diverse households). These changes have occurred especially in urban areas (Buitrago-Esquinas et al. 2023). In urban destinations such as Barcelona, Venice, Amsterdam, Berlin, Kyoto, and many others, the well-being residents and the quality of tourist experiences are under strain due to the excessive number of visitors (UNWTO et al. 2018; Seraphin et al. 2018; Cheer et al. 2019; Milano et al. 2019). However, the excessive number of visitors is not the only factor creating conflict and environmental deterioration in these destinations (Koens et al. 2018). Rising rents and real estate prices, touristification, gentrification, a standardized image of place, the overuse of infrastructure and services, the loss of cultural identity and traffic congestion, all combine to undermine social relations and local resources (Butler 2018; Milano 2018; Blázquez-Salom et al. 2021; Santos-Rojo et al. 2023). These negative externalities are certainly not only found in urban areas. As Peeters et al. (2018) point out, overtourism is also observed in other places such as coastal areas, rural areas, heritage and cultural attractions, protected areas and islands. These different territorial contexts stand out for having lost control of tourism management and crossed sustainability thresholds. Many of these are today taking action to create new values (Celata and Romano 2020). Some of the strategies implemented locally can be identified in the 5Ds model of 'Deseasonalization, Decongestion, Decentralization, Diversification and Deluxe Tourism', which however promote temporary solutions (Milano 2018). It is therefore desirable for a destination to promote a significant paradigm switch in tourism planning by involving all the actors in the sector. As suggested by Mendoza de Miguel et al. (2023), one additional solution is to create knowledge pathways and encourage the conscious transformation of residents and visitors (Corna Pellegrini 2008).

Set in this framework, this study proposes a methodology to evaluate the spatial distribution and autocorrelation of a set of tourism indicators to understand the potential for overtourism in insular, island contexts. Validation of this methodology is conducted in the island of Sardinia, a region of Italy representing a relevant tourist destination among Mediterranean islands.

Based on the research needs, the rest of the paper is structured as follows: after the introduction, the authors propose a comprehensive conceptualization of overtourism and an overview of the phenomena in islands; a methodology section describes the application of geospatial representation techniques and the LISA spatial autocorrelation data; this is followed by a description of the study area with the related data and the study results. The last section is dedicated to discussion and conclusions.

## Conceptualization of overtourism

The various combinations derived from tourism (transport and tourism; catering and tourism; culture/art and tourism; agri-food and tourism, etc.) demonstrate how tourism is complementary to other sectors. Tourism is one of the largest industries in many countries, as evidenced by employment in tourism-related industries and in food and beverage services, as well as its share to the total GDP. In 2024, the World Travel & Tourism Council (WTTC) announced a record-breaking year for Travel & Tourism, with the sector's global economic contribution reaching an all-time high of $11.1 trillion (WTTC 2024), surpassing the pre-pandemic level of $10.3 trillion.

Although tourism has long been considered an alternative development model, capable of replacing heavy industry-based models (Margaryan 2017), it also has complex negative environmental impacts, including significant global carbon emissions that affect ecosystems and the climate (Herre et al. 2023). Concerns about visitor numbers and human impact on some destinations are not new (Perkumiene and Pranskuniene 2019). The term overtourism was popularized in 2016 by the platform SKIFT.com, which used it in reports to describe situations in which mass tourism depletes, homogenizes and consumes destinations (O'Regan et al. 2022; Gainsforth 2023). The term was later given a clearer definition in a 2018 report by the UNWTO (WTO 2019).

The focus on this phenomenon has increased exponentially in recent times as, contrary to expectations, tourism has continued to grow after the Covid-19 pandemic (Biella 2022), particularly in certain destinations. This growth in tourist numbers is also the result of changes affecting the transport-related aspects of the tourism sector. The rise of low-cost airlines has contributed significantly to the increase in passenger numbers on routes and to destinations worldwide (Capocchi et al. 2019) and is linked to the steady growth of cruise tourism. However, cruise tourism carries with it the effects and dangers of 'mass tourism' and 'hit-and-run tourism' more than other forms of tourism. However, overtourism is not the same as mass tourism, because some areas are able to cope with the growing number of tourists (Postma and Schmuecker 2017). The widespread concern of overtourism, which often results in anti-tourist sentiment, is more related to those situations where tourism becomes a serious inconvenience for local communities, transforming their lifestyles, causing environmental changes and a loss of authenticity in a place (Leka et al. 2024). In these cases, the collective costs increasingly outweigh the benefits of tourism (Santos-Rojo et al. 2023).

The conceptualization of potential risks of overtourism in relative destinations, understood within a socio-ecological system (Wei et al. 2018; Pásková et al. 2021) is correlated to three main stages (Fig. 1):

1. Definition of the threshold or risk level for each destination (the maximum destination burden), based on the potential environmental, economic and social risks generated by tourism development in the destinations concerned.
   Different disciplines have conceptualized and calculated carrying capacity in different ways. Many studies trace its origins to the work of ecologists, who indicated the maximum number of individuals that could be supported in an environment without compromising the ability of the area to support future generations (Odum 1971; Rees 1992). In the context of the recreational sector, the concept found its roots in the 1950s, when concerns about the sharp increase in visits to US national parks and protected areas led local actors to seek 'limiting' solutions to protect the quality of recreational activities offered. Subsequently, and with greater frequency in the 1980s, the concept began to be applied in tourism management (Meadows et al. 1972; Butler 1980; Getz 1983; O'Reilly 1986; Swarbrooke 1999; Laudati 2010). Today, as in the past, it seems very complex to define the threshold within which, for each destination, the number of arrivals and visitors can be considered a sustainable form of tourism and, on the other hand, beyond which the impact is such that we have to speak of overtourism (He et al. 2023; Galeano et al. 2023). The challenge is therefore to understand the limits within which tourism can be recognized as an opportunity for the development and enhancement of resources, rather than as a source of commodification of values, in order to find a balance between the demands of the sector and the needs of local communities.

2. Development of methodologies for the measurement of tourist overcrowding in different destinations, considering a set of factors/indicators representative of the environmental, economic and social dimensions.
   The tourist pressure may have a negative impact on the environment (soil erosion, loss of biodiversity, $CO_2$ emissions) (Sun et al. 2024), infrastructure and the socio-economic fabric of local communities (Helgadóttir et al. 2023; Ceschin 2024). Environmental issues, as well as cultural and social issues related to the potential alteration or disruption of traditional lifestyles, cultural erosion and commodification, are the main challenges to achieving more responsible and inclusive tourism (EPRS 2017; Ministero del Turismo 2024). Environmental issues include environmental degradation, pressure on essential resources such as water and energy, increased waste generation,

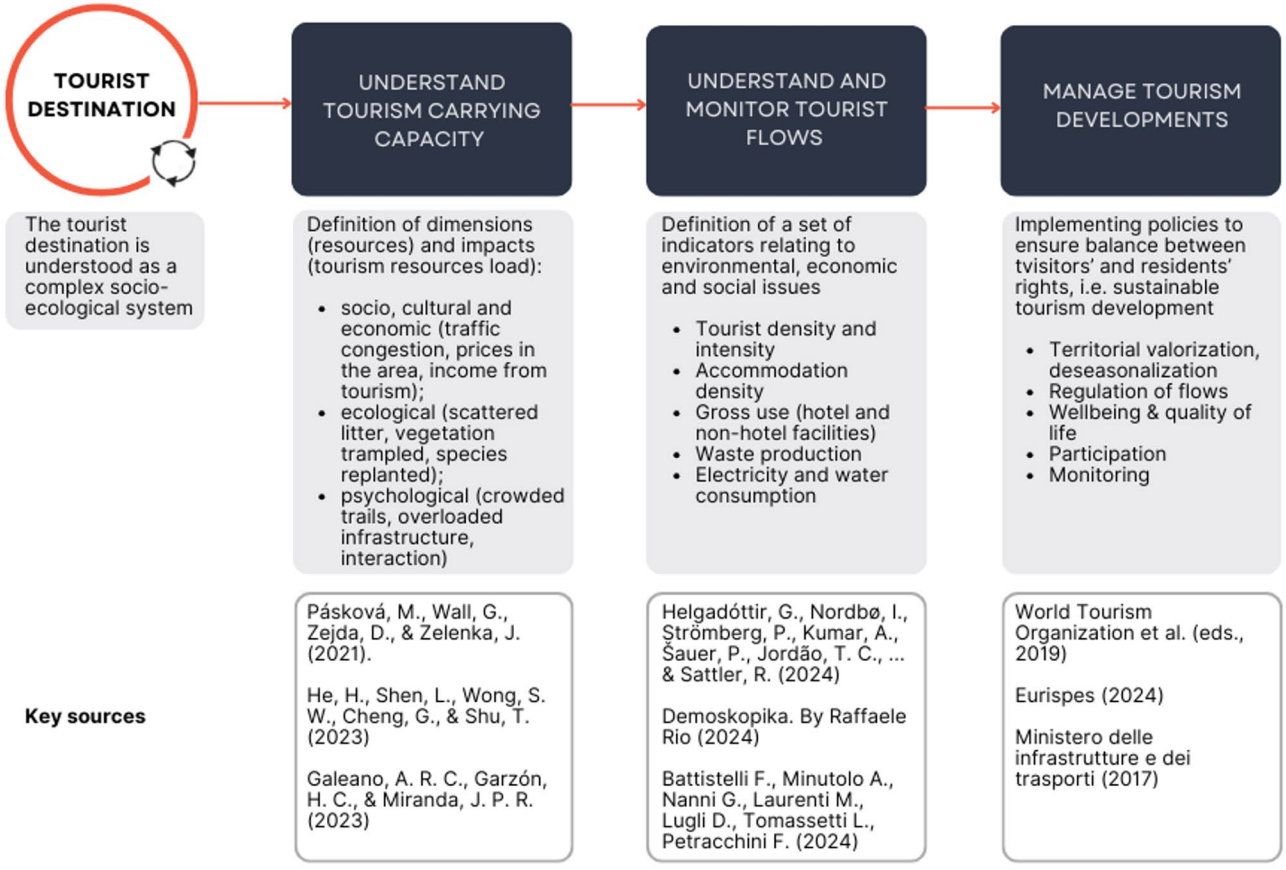



**Fig. 1** Conceptual framework for understanding and managing the phenomenon of overtourism. Authors: G. Balletto and M. Ladu

air pollution and carbon footprint. These issues can lead to climate change, ecological imbalances, damage to natural habitats, and a threat to wildlife. It is estimated that aviation alone accounts for 2.5% of global $CO_2$ emissions, caused by the growing demand for domestic and international commercial passenger flights (Ritchie 2024).

Tourism may also encroach upon the local environment and culture. For example, by raising consumer prices and displacing local communities, tourism can lead to social inequalities. Another important threat to consider is the potential phenomenon of exploitation of the population due to the poor working conditions offered, especially to the most vulnerable. Unsurprisingly, sustainable tourism research has increasingly focused on social issues such as the relationship between residents' quality of life and community resilience through adaptability (Helgadóttir et al. 2019, 2023). In this sense, the number of arrivals and the average length of stay of visitors represent a determining factor. These issues require particular attention especially when faced with the threat of overtourism (Buitrago and Yñiguez 2021; Mihalic and Kuščer 2021; Capocchi et al. 2019).

In Italy, tourism is a significant component of GDP (Banca d'Italia 2024). The ratio of direct tourism gross value added to total gross value added of the economy shows that Italy recorded one of the highest values in Europe in 2022. Tourism's share of total gross value added was equal to 6.2% (Eurostat 2023). In 2023, the total contribution of travel and tourism to Italy's GDP amounted to nearly 215 billion euros, that is 1.8% higher than in 2019, the year before the onset of the Covid-19 pandemic (WTTC 2024). The total contribution of these industries is expected to reach 223.1 billion euros in (WTTC 2024). However, this important contribution to the Country's economic development is offset by the risk of overtourism. This requires the adoption of evaluation methods that take into account the exploitation of local resources and, more generally, a series of factors that threaten the ecological balance (Christin 2019).

In this context, the General Index of Tourist Overcrowding, which is currently in an experimental phase in Italy, uses five indicators to assess the overall level of tourist overcrowding through a combination of indicators reflecting different dimensions of the

impact of tourism on Italian cities and regions at a provincial level: tourist density, accommodation density, tourist intensity, gross utilization and the share of urban waste generated by the tourism sector (Demoskopika 2024). In this sense, the index helps to understand the impact of tourism on the population, the use of accommodation infrastructure, the intensity of tourist interaction with residents and, finally, the impact on the environment in terms of waste management. Italian metropolitan provinces/cities (Balletto et al. 2020) have been classified into three risk levels: very high, high, moderate. The index is presented as a tool to support institutional decision-makers at various levels in the management of the phenomenon, providing data and territorial analyses to help reconcile the economic needs driving the tourism sector with long-term environmental and social sustainability.

3. Draft of policy proposals (strategies and actions) for better understanding and management of the phenomenon for the benefit of visitors and residents, in balance with ecosystems, with the involvement of local communities and key stakeholders.
There are various policies in place to promote sustainable tourism models, both nationally but also at the level of individual destinations. The UNWTO recently produced a report analyzing 18 cities around the world as case studies and proposing 11 strategies and 68 actions to improve the understanding and management of tourism in urban destinations, benefiting both visitors and residents. This is in line with the New Urban Agenda and the Sustainable Development Goals (WTO 2019).
In Italy, EURISPES (2024) has recently promoted 20 operational proposals to manage such a complex phenomenon, thus balancing the multiple rights of travelers and the local community. The operational proposals can be divided into 5 macro themes:

- Public policy and governance (focus on territorial valorization and deseasonalization);
- Regulation of flows and sustainable tourism (taxes, incentives and regulations);
- Well-being and quality of life (focus on local community benefits from tourism and improvement of infrastructures and facilities);
- Participation (engagement of the local community, stakeholders and visitors);
- Monitoring and continuous improvement.

Regarding the first macro-theme, the Italian government intends to strengthen the transport-tourism chain by investing in internal and external territorial continuity, in order to create a network of accessible destinations through the concept of Mobility as a Service (MaaS) (Italia - T.T.S. 2021). MaaS solution promotes sustainable intermodal mobility favoring the use of public transport, thus reducing the decongestion of tourist flows in the main tourist destinations (Italy is second in Europe in terms of seasonality), enhance the cultural, sporting, environmental and food and wine attractions spread throughout the country, and generate positive effects in terms of the use of financial and human resources (Ministero delle infrastrutture e dei trasporti 2017). The indicators, strategies and actions promoted at international and national levels are not universal, given the diversity and complexity of the causes and effects of overtourism in different destinations. As a matter of fact, there is no one-size-fits-all solution for overtourism. Even in the most sensitive contexts, such as islands (Battistelli et al. 2024), knowing the specificities and sensitivities of the territory to develop place-based policies in collaboration with stakeholders and local policymakers is certainly the most effective way forward (Peeters et al. 2018).

## Overtourism in Islands

Islands represent complex realities that make them vulnerable and often dependent on the mainland, but they also demonstrate resilience by managing to survive the difficulties of geographic isolation. The popular imagination mostly associates insular spaces with the sea. Coastal areas on many islands have experienced major transformations related to the services sector, and very often suffer from invasive forms of tourism (Amaro García and Battino 2021).

Tourism offers islands a strong economic development opportunity to increase employment, generate economic activity, reduce poverty and build skills among the population. Indeed, island territories (or archipelagos) exhibit strong dependence on tourism, with some having adopted strategies for attracting visitors and developed strong economies due to the related activities (Figueroa and Rotarou 2021). Examples of such success stories include the Caribbean small states, but also closer to home are the independent island states of Cyprus and Malta and other island dependencies in the Mediterranean (e.g. Spanish Balearic Islands and the Greek islands). This dependence and growth, especially in post-pandemic months, has resulted in negative externalities which are linked to the small size of the territory and the local population, leading to potential saturation, environmental degradation and a subsequent decline in the tourism product (decreased attractiveness). This is certainly the case for small and densely populated islands

like Malta with a land area of just 316 sq km, a fast-growing resident population of over 500,000 and an annual tourist population reaching a record 3,000,000, generating €2.7 billion in total tourism expenditure in 2023 (National Statistics Office 2024). The islands' tourism national strategy (2021–2030) recognizes the challenges of overtourism and lists five reforms to counter the negative impacts including the need for carrying capacity assessment and visitor management, promotion of off-peak tourism, environmental sustainability initiatives, a diversification of tourism offerings and infrastructure for carrying capacity monitoring (OECD 2024, p. 312).

Other islands have been more proactive in recognizing and limiting overtourism. In 2007, the Ecuadorian government put under emergency status the Galapagos Islands and instituted strategies to control overtourism. UNESCO also added them to the List of Natural Heritages in Danger and only removed them in 2010 whilst insisting on the need to address unsustainable tourism development (Burbano et al. 2022). Entry taxation and limits on the number of nights have emerged as measures introduced to limit impact on island destinations such as Bali (Indonesia), Easter Islands and the Galapagos (Figueroa and Rotarou 2021). The Spanish Balearic islands, more specifically Majorca, the largest island has been a leading island destination in the Mediterranean and studies have identified extensive impacts of overtourism on the island's limited land resources, transport system, environment and biodiversity and culture, with terms such as 'island invasion' being used for over 30 years to highlight the impact of international tourists on the islands (Bardolet and Sheldon 2008; Garau-Vadell et al. 2014). Indeed, the increased awareness of negative externalities has resulted in protests by residents demanding changes to the tourism-dependent economic model of the islands (Ramis 2018).

Overtourism is a growing phenomenon in the Italian islands too, threatening the sustainability of these fragile ecosystems. Among the most relevant cases are the islands of the Tuscan archipelago such as Elba, Campania islands (Capri, Ischia and Procida) and some Sicilian islands (Lampedusa and Aeolian), and Sardinia Island and the relative archipelagoes, where the limited resources and infrastructure amplify the negative effects of mass tourism. In all these cases, particularly the coastal areas face challenges related to managing tourist flows to preserve natural beauty and livability for local communities. The latter are areas of transition between land and sea. For several interrelated reasons, these areas are particularly sensitive and represent fragile ecosystems that are vulnerable to human intervention and climate change.

In this sense, Sardinia (Italy) represents an interesting case study to evaluate the potential phenomenon of overtourism through the method proposed by this study.

## Methodology

According to the literature review proposed in the previous section (Conceptualization of overtourism) that led to defining a conceptualization of potential risks of overtourism in relative destinations (Fig. 1), the four-step iterative process of the Deming Cycle (Plan-Do-Check-Act) (Fig. 2) is used in this study to understand the potential of overtourism. The Deming Cycle provides a flexible method that can adapt successfully to multiple realities (Isniah et al. 2020), including that of tourism:

- PLAN: Planning to develop a tourist destination, conceived as a complex socio-ecological system.
- DO: Definition of the threshold or risk level for each destination (the maximum destination burden), based on the potential environmental, economic and social risks generated by tourism development in the destinations concerned.
- CHECK: Development of methodologies for the measurement and monitoring of the level of tourist overcrowding in different destinations, considering a set of factors/indicators representative of the environmental, economic and social dimensions.
- ACT: Policy proposals (strategies and actions) for better understanding and management of the phenomenon for the benefit of visitors and residents,

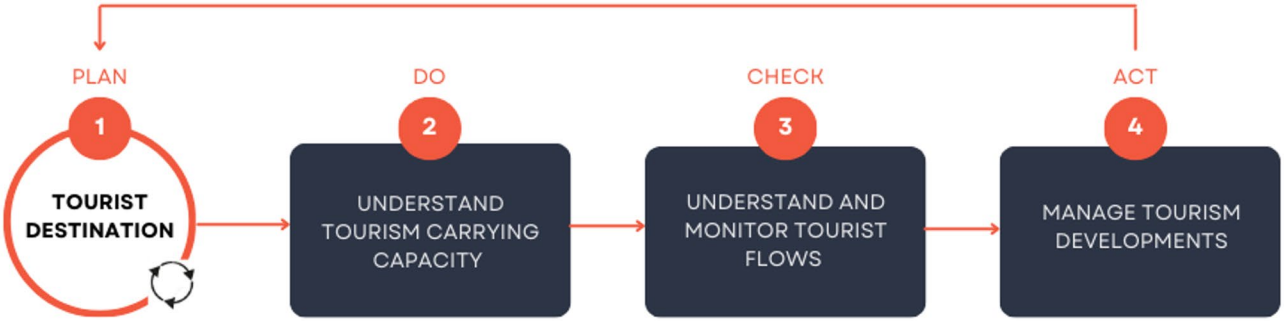



**Fig. 2** The deming cycle (Plan-Do-Check-Act) proposal. Authors: G. Balletto and M. Ladu

in balance with ecosystems, through the involvement of local communities and key stakeholders.

This study focuses on the third step (Check) of the Deming Cycle. The methodology aims to understand the potential overtourism phenomena through the proposal of a series of indicators and related geospatial representation using Local Indicators of Spatial Association (LISA) to identify spatial clusters and outliers in geographic data. This approach is intended to support policies that promote a more sustainable tourism framework, specifically by improving the temporal and spatial distribution of tourism activities (Anselin 1995).

Building on the work of several authors (Helgadóttir et al. 2023; Battistelli et al. 2024), and other sources (Demoskopika 2024; ISTAT 2024), this research integrates a set of indicators on tourist overcrowding and the spatial dimension of the island region, the coastline and the coastal area (Table 1). The indicators can be identified in two areas: tourism and environment.

The first area concerns the main tourism indicators (tourist density and intensity, accommodation density and gross use of hotel and non-hotel facilities), linked to the island area (km²) and the coastal area (km²). Square kilometer (km²) is the spatial dimension of the insular study area, which can be applied in several administrative dimensions (municipality, province, metropolitan city or region), and/or airport/port regions. The study analyses also tourist load and accommodation load reported to the coastline (km).

The number of tourist nights, defined in this study as "presences", is a key figure in the development of some of these indicators. The number of nights spent by tourists in a destination is also used to calculate the equivalent number of inhabitants. This measure allows for the calculation of the weight of tourists in terms of the resident population, over the 365 days of the year. This metric is particularly useful in the management of tourist flows as it shows the real anthropogenic load in a destination and to plan services according to actual demand. The second domain concerns the main environmental KPIs representative of the tourism phenomenon: waste production; water consumption; energy consumption; $CO_2$ production from aviation and maritime transport (Sun et al. 2024).

All indicators in the environment sector refer only to the coastal area ($km^2$) except for the $CO_2$ production indicators. As a matter of fact, the spatial distribution of $CO_2$ production from aviation (https://flightemissionmap.org/) and maritime transport refers to the part related to take-off and landing (for aviation) and mooring (for shipping) which mainly affects areas close to port and airports. $CO_2$ production from aviation and maritime transport is calculated for passengers according to the formula: g*km*passenger, where 'g' is the amount of $CO_2$ production, and 'km' is the overall average length of routes to and from ports and airports in the insular region. These indicators regarding the environmental impact of transport (air, maritime) are necessarily linked to the potential overtourism phenomena because tourists represent most of all passengers in tourist destinations.

**Table 1** KPIs on tourism data and environmental data in two Spatial dimensions, coinciding with the Island region and the coastline/area. Authors: G. Balletto and M. Ladu

| Domain/Data | KPIs Insular Region (municipality, province, metropolitan city or region, airport/port zone) | KPIs Coastal line or Coastal area | SDGs |
|---|---|---|---|
| Tourism data | **Tourist density** (presences/km²) | **Tourist loading the coastline** (tourist presences/km) | **8**, **11** |
| | **Accommodation density** (beds/km²) | **Accommodation load in the coastline** (beds/km) | |
| | **Tourist intensity** (presences/population) | **Tourist intensity in the coastline** (presences/population)/km | |
| | **Gross use (hotel and non-hotel)** [(presences/(beds + 365)] 100 | **Gross use (hotel and non-hotel) in the coastal area** [(presences/(beds + 365)] 100 | |
| Environmental data | **Waste production per tourist** [(Tons/population) - (Tons/( presences/365 + population)] | **Waste production per tourist in the coastal area** [(Tons/population) - (Tons/( presences + population)/365)] | **12** |
| | **Water consumption per tourist** [(l/population)-(l/( presences + population)/365)] | **Water consumption per tourist in the coastal area** [(l/population) -(l/( presences + population)/365)] | **6** |
| | **Energy consumption per tourist** [(KWh/population) - (KWh/(presences + population)/365)] | **Energy consumption per tourist in the coastal area** [(KWh/population) - (KWh/(presences + population)/365)] | **7** |
| | **CO2 production from aviation transport** (g * km * passenger)/km² | **CO2 production from aviation transport in the coastal area** (g * km * passenger)/km² | **13**, **15** |
| | **CO2 production from maritime transport** /km² (g * km * passenger) | **CO2 production from maritime transport in the coastal area** (g * km * passenger)/km² | **13**, **14** |

Table 1 describes the set of indicators conceived as KPIs of the tourism phenomena in the related spatial contexts.

The definition of approaches and methods to understand the dynamics of tourism development and to monitor its effects on people and places represents a real challenge, especially in fragile and sensitive contexts such as insular ones (Marras and Ladu 2022; Ladu et al. 2023).

This methodological approach is also in line with the Sardinia region's spatial planning regulation, which recognizes the coastline as a parameter to evaluate the tourist carrying capacity.

This study uses spatial analysis techniques to understand the spatial dimension of the tourism phenomenon, expressed through the set of KPIs here described (Table 1).

## LISA Spatial autocorrelation data

Spatial autocorrelation analysis can be applied to data or indicators associated with a set of contiguous geographical units. This technique is valuable for evaluating local effects and identifying spatial clusters based on both attribute and geographical data. The principle behind spatial autocorrelation is that spatial proximity can influence the phenomena being studied. Data associated with geographical units can be influenced by both their spatial configuration and proximity, as well as by the attribute values assigned to those units.

The principle that "nearby things are more related than distant things," as articulated by Tobler (1970), while intuitively appealing, has seen a resurgence in scholarly attention (Sui 2004). Spatial autocorrelation analysis examines the relationship between a variable's value at a given location and the values of that variable in neighboring locations.

In the present study, spatial autocorrelation techniques are used to identify the spatial patterns of the phenomenon of overtourism in its different dimensions. More precisely, spatial patterns refer to specific geographical areas exhibiting varying levels of similarity in the values of the analyzed indicators. Formally, spatial autocorrelation is defined as follows (Lee et al. 2000):

$$SAC = \frac{\sum_{i=1}^{N} \quad \sum_{j=1}^{N} \quad c_{ij} w_{ij}}{\sum_{i=1}^{N} \quad \sum_{j=1}^{N} \quad w_{ij}}$$

Where:

- i and j are two objects or events in space.
- N is the number of objects or events.
- cij is a degree of similarity of attributes i and j.
- wij is a degree of similarity of location i and j.

From the general formula it is possible to derive two indices as the Geary C Ratio (Geary 1954) and the Moran Index I (Moran 1948). Defining xi as the value of object i attribute; if cij = (xi – xj) 2, Geary C Ratio can be defined as follows:

$$c = \frac{(N-1)(\sum_i \quad \sum_j \quad w_{ij}(x_i - x_j)^2)}{2(\sum_i \quad \sum_j \quad w_{ii}) \sum_i \quad (x_i - \underline{x})^2}$$

If $cij = (xi - x)(xj - x)$, Moran Index I can be defined as follows:

$$I = \frac{N \sum_i \quad \sum_j \quad w_{ij}(x_i - \underline{x})(x_j - \underline{x})}{\sum_i \quad \sum_j \quad w_{ij}(x_i - \underline{x})^2}$$

Moran's I and Geary's C are frequently used to analyze spatial autocorrelation, as illustrated by recent applications in Italian research (Murgante and Borruso 2012). These indices are closely related, with the key distinction being the calculation of the cross-product term in their respective numerators. Moran's I employ deviations from the mean, whereas Geary's C uses direct computation. While both indices provide a global measure of spatial autocorrelation, revealing whether it exists across the entire study area, they do not identify specific locations of clustering. For this purpose, Local Indicators of Spatial Association (LISA), such as the local Moran index developed by Anselin (1988; 1995), are employed. This value represents the sum of all local indices and is proportional to Moran's I:

$$\sum_i \quad I_i = \gamma * I$$

The index is calculated as follows:

$$I_i = \frac{(X_i - \underline{X})}{S_X^2} \sum_{j=1}^{N} \quad (w_{ij}(X_j - \underline{X}))$$

The index facilitates the assessment of the similarity between each observation and its neighbors for all locations. Five possible combinations are derived from its application:

- Hot spots are areas with high values of the phenomenon that are also surrounded by areas with high values (High-High, H-H). The H-H designation indicates this high-value clustering.
- Cold spots, as areas with low values of the phenomenon and a low level of similarity with its surroundings (Low-Low L-L).

- Potentially spatial outliers, with high values of the phenomenon and a low level of similarity with its surroundings (High-Low H-L).
- Potentially spatial outliers, with low values of the phenomenon and a high level of similarity with its surroundings (Low-High L-H).
- No significant spatial autocorrelation.

A key advantage of LISA is its provision of an effective measure of the degree of relative spatial association between each territorial unit and its contiguous elements, thereby elucidating the nature of spatial concentration and clustering. A spatial weight matrix, crucial for the above-mentioned equations, is constructed using weights (wij) that define neighborhood relationships. These weights are binary: wij = 1 if spatial units i and j are neighbors, and wij = 0 otherwise. Neighborhood is typically defined based on contiguity. For aerial units, this often means sharing a common border of non-zero length (O'Sullivan and Unwin 2010). Rook and Queen contiguity are standard methods for determining neighborhood.

More precisely, the study proposes GeoDa, a free, and open-source software tool for spatial autocorrelation to apply the method, selecting "Queen contiguity" to create the weights file as "queen" can move horizontally, vertically, or diagonally.

## Study area

The Sardinia Region is the second-largest island in the Mediterranean Sea (after Sicily and before Cyprus) and the third in Italy (Fig. 3).

With a population of 1,569,832 inhabitants (January 1, 2024) and a surface area of 24,090 km², the Sardinia is among the Italian regions with the lowest population density, which stands at around of 66 inhabitants/km², a value sure to increase with time, given that the Sardinian population is constantly decreasing. The island lost over 88,000 inhabitants between 2016 and 2024. In 2023, the number of deaths (18,563) was more than double the births (7,231), resulting in a negative natural balance of -11,332.

The current configuration of the administrative geography (Balletto et al. 2021) includes four provinces (Nuoro, Oristano, Sassari, and South Sardinia), one Metropolitan City (the Metropolitan city of Cagliari) and 377 municipalities. More than half of the population lives in the province of Sassari (30.1%) and in the Metropolitan City of Cagliari (26.7%). The province of South Sardinia, with more than 330 thousand inhabitants, accounts for 21.1% of the regional population, while the provinces of Nuoro and Oristano host 12.5% and 9.5% respectively.

The main gateways to ensure connections to and from Sardinia for both the local population and city users visiting the island consist of eight ports (Cagliari, Olbia, Porto Torres, Golfo Aranci, Portovesme, Oristano, Santa Teresa Gallura, Arbatax) and three international airports (Cagliari, Olbia, Alghero). Ports and airports are also the main nodes for establishing a strong relationship with the Trans-European Networks, more generally, with the transport network in the Mediterranean area (Fancello 2024). As regard the intra-regional connectivity (Ladu et al. 2024), the transport offer consists of around 9,000 km of road network and 427 km of Italian railway network (RFI), in addition to which the railway network managed by the Sardinian Regional Transport Company (ARST) and the tourist railway networks (Trenino Verde) should be considered (Sardinia Region 2008).

The Sardinia Region has a strong tourist sector, characterized by a marine-seaside tourism model, which reaches its peaks in the summer season, mainly affecting the coastal areas (Sardinia Region 2018). According to the regional statistics on arrivals and departures (Sardegna Mobilità - Bollettino Arrivi e Partenze) in 2023, the number of tourist arrivals were 7,285,690 (4,743,283 at




**Fig. 3** The study area. Sardinia Region. All authors

airports and 2,542,407 at ports) (Sardinia Region 2022). Figure 4 shows the tourist arrivals, comparing December and August 2022, thus confirming the peaks of the summer season along the coastal areas. Almost all the over 7 million arrivals were concentrated in the summer season (6,166,843), and more than half of these were recorded in June, July and August (3,755,834). The International Air Transport Association (IATA) identifies the northern summer period starting on the last Sunday in March, while the winter starting on the last Sunday in October.

Although the Regional Strategic Plan for Tourism (2023–2025) (Sardinia Region 2023) intends to diversify the tourist offer (Battino et al. 2018; Balletto et al. 2021), seasonal tourism prevails over other forms of tourism in Sardinia (Balletto et al. 2024). The more recent data reveal an increase in tourist flows in 2024: 4,007,181 arrivals were recorded at the ports and airports of the island in the three peak months (June, July and August) (Sardinia Region 2024b).

Other important considerations arise from the regional census on the annual movements of customers in accommodation facilities, which provides information on arrivals and number of nights recorded in the municipalities each month. The regional census, which took accommodation facilities (hotels and non-hotel facilities) as the unit of detection, reveals that 3,902,458 arrivals and 16,585,664 presences were recorded in 2023, with an increase of 4.40% and 2.40% respectively compared to 2022 (Sardinia Region 2024b). The first thirty municipalities that recorded the highest number of arrivals and presences are almost all located in coastal areas, confirming the preference for seaside tourist destinations. Moreover, tourists are distributed as follows: 9,515,977 in hotel facilities; 7,069,687 in non-hotel facilities. The increase in arrivals and stays in private rental accommodation (non-hotel facilities), of 30.66% and 35.84% respectively, represents the most significant data compared to 2022.

According to the Regional Register of Accommodation Facilities and private accommodation (July 2024) (Sardinia Region 2024a), approximately 33,000 accommodation facilities were officially registered in Sardinia, and 31,000 of these are non-hotel facilities. Figure 5 shows the number of beds for hotel and non-hotel facilities for 2023.

The tourist accommodation offer in Sardinia has undergone a profound evolution in recent years, adapting to the new needs of tourists and market trends. In the last 10 years, the number of non-hotel facilities such as B&Bs, farmhouses, private rental accommodation or holiday homes has grown rapidly, reshaping the traditional profile of the tourism offer, which was previously dominated by hotels (Bussu 2022).

Within this framework, some of the features of overtourism are highlighted in the insular context of Sardinia. More precisely, it would be more appropriate to

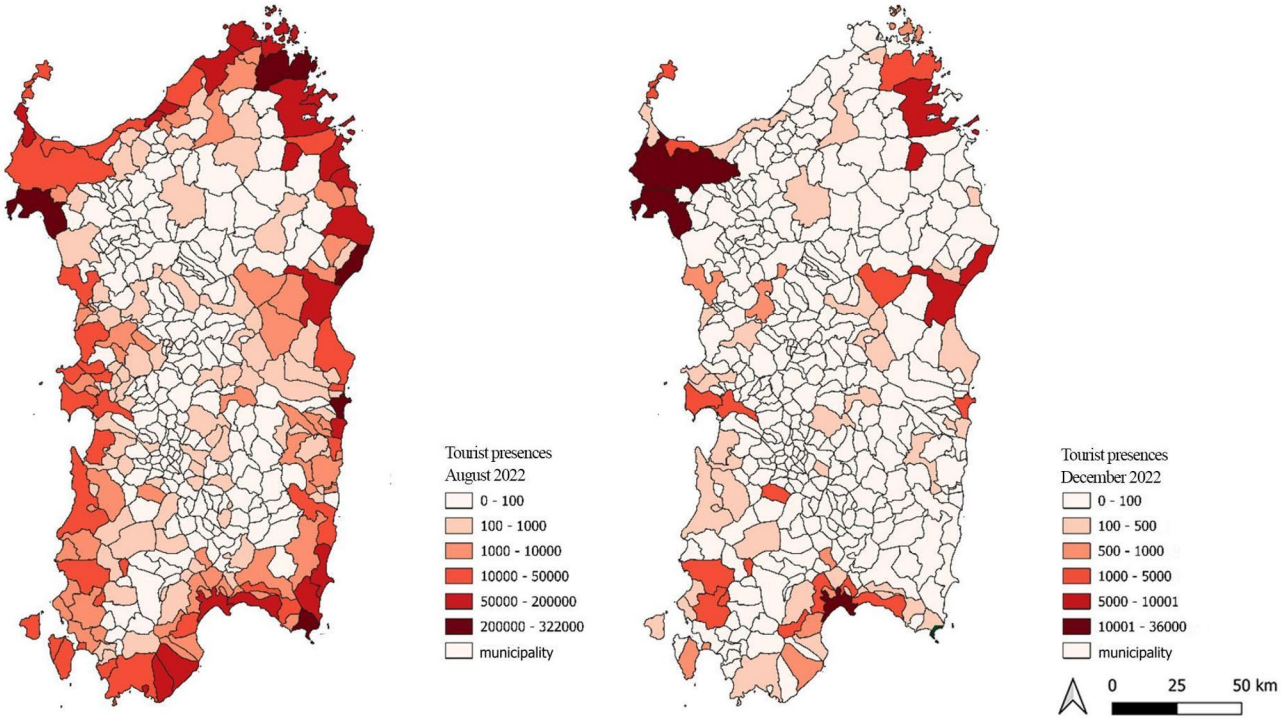



**Fig. 4** Spatial distribution of presences in August 2022 (left) and December 2022 (right). Data source: (Sardegna Turismo - Osservatorio del turismo). Authors: G. Balletto and M. Ladu

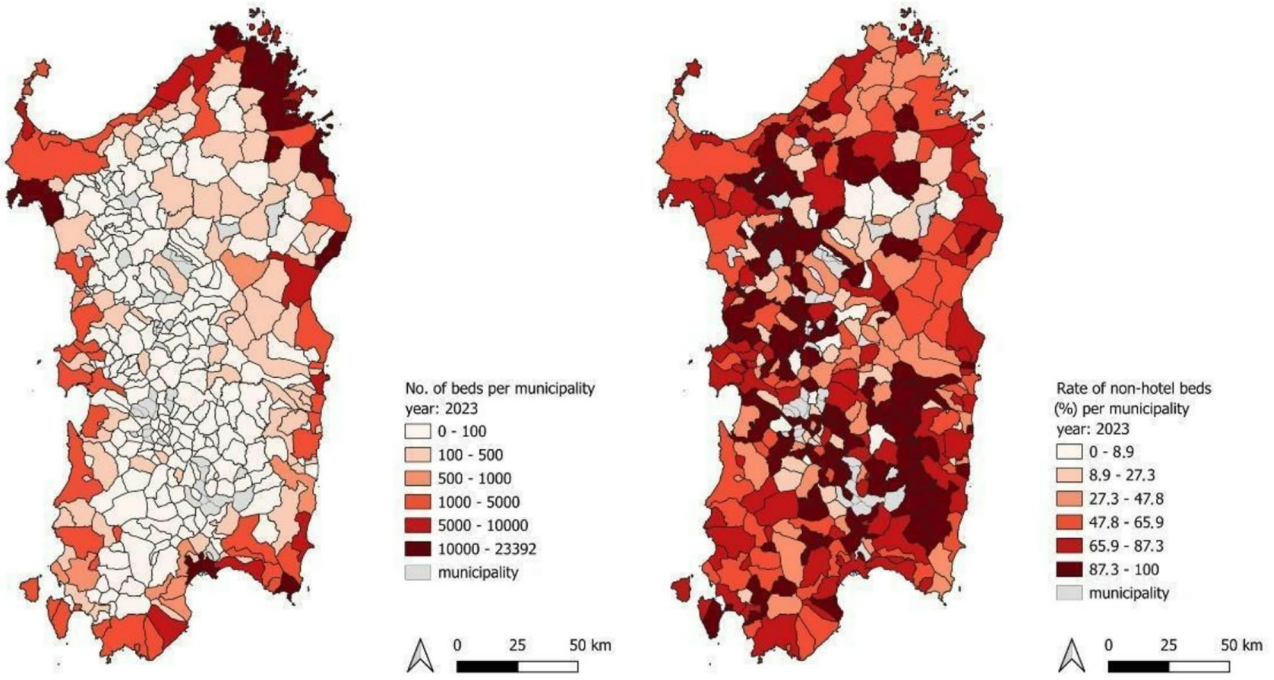



**Fig. 5** Spatial distribution of the number of bed places (left) and the rate of non-hotel beds (%) per municipality (right). The gray color indicates the municipalities for which the data is not available. Authors: G. Balletto and M. Ladu. Data source: (Sardinia Region 2023 and 2024b)

**Table 2** Geographical data to represent and monitor the tourist phenomenon in the Sardinia region. Authors: G. Balletto and M. Ladu

| Geographic data | Source | Year |
|---|---|---|
| Population | ISTAT - Resident population (https://demo.istat.it/) | December 31, 2022 |
| Administrative area ($km^2$) and boundaries | ISTAT - Boundaries of Administrative Units ( https://situas.istat.it/web/#/home) | January 1, 2024 |
| Coastline (km) | ISTAT - Coastal Census Sections (https://www.istat.it/non-categorizzato/sezioni-di-censimento-litoranee/) | December 31, 2013 |

conceptualize overtourism as concentrated both time and space: in time because the majority of tourist movements are recorded in the summer season, with peaks in June, July and August; and in space, because tourists are mainly concentrated in coastal areas, which also record an exponential growth in the number of non-hotel accommodations.

This kind of overtourism in Sardinia generates negative impacts on the environment (soil erosion; pressure on essential resources such as water and energy; waste production; air pollution; climate change; ecological imbalances; loss of biodiversity), as well as on infrastructures and local communities.

## Data

The geographical data used to represent and monitor the tourist phenomenon in Sardinia (population, administrative boundaries and coastline), with the relative source are reported in Table 2. For each indicator proposed by the methodology, the data and the related sources are then detailed in Table 3.As regard the tourism data, the main data source for calculating the number of arrivals and presences in Sardinia is the database on accommodation capacity and tourist movements provided by the data collection and processing information system SIRED (Sistema Informativo di Calcolo e Elaborazione Dati). This data set is provided by the Sardinian Region to simplify the management of tourism flows, the regulation of the numerous accommodation facilities and their fiscal and statistical obligations, but also to ensure public safety. Data related to the arrivals and stays recorded each month in each municipality can be downloaded in csv format from the regional tourism dashboard "Sardegna Turismo - Osservatorio del turismo, artigianato e commercio" (http://osservatorio.sardegnaturismo.it/it). *Arrivals* represent the total number of people who, in a given period (for example during a year or a month, that is the update frequency of the data), have stayed at least one night in a hotel or non-hotel accommodation facility. Therefore, the number of arrivals represents a measure of the tourist flow present at each destination.

On the other hand, presences indicate the number of nights spent by city users (mainly tourists) in

**Table 3** Data sources and year related to each KPIs proposed by the methodology. Compiled by authors: G. Balletto and M. Ladu

| Domain/data | KPIs Insular Region | KPIs Coastal line/area | Data | Source | Year |
|---|---|---|---|---|---|
| Tourist data | **Tourist density** (presences/km$^2$) | **Tourist load in the coastline** (presences/km) | Tourist Presences (No) | *Sardinia Region_Sardegna turismo* | 2022 |
| | **Accommodation density** (beds/km$^2$) | **Accommodation load in the coastline** (beds/km) | Beds per accommodation facility (hotel and non-hotel facilities) (No) | *Sardinia Region_Sardegna turismo* | 2022 |
| | **Tourist intensity** (presences/population) | **Tourist intensity in the coastline** (presences/population)/km | Tourist Presences (No) | *Sardinia Region_Sardegna turismo* | 2022 |
| | | | Population | ISTAT - Resident population (https://demo.istat.it/) | 2022 |
| | **Gross use (hotel and non-hotel)** [(presences/(beds + 365)] 100 | **Gross use (hotel and non-hotel) in the coastal area** [(presences/(beds + 365)] 100 | Tourist Presences (No) | *Sardinia Region_Sardegna turismo* | 2022 |
| | | | Beds per accommodation facility (hotel and non-hotel facilities) (No) | *Sardinia Region_Sardegna turismo* | 2022 |
| Environmental data | **Waste production per tourist** [(Tons/population) - (Tons/(presences + population)/365)] | **Waste production per tourist in the coastal area** [(Tons/population) - (Tons/(presences + population)/365)] | Waste production (tons) | ISPRA, Catasto Nazionale *Rifiuti* | 2022 |
| | **Water consumption per tourist** [(l/population) -(l/(presences + population)/365)] | **Water consumption per tourist in the coastal area** [(l/population) -(l/(presences + population)/365)] | Water consumption (mc) | Abbanoa Spa (closed data) | - |
| | **Energy consumption per tourist** [(KWh/population) - (KWh/(presences + population)/365)] | **Energy consumption per tourist in the coastal area** [(KWh/population) - (KWh/(presences + population)/365)] | Energy consumption (KWh) | Enel Energia (closed data) | - |
| | **$CO_2$production from aviation transport** (g * km * passenger)/km$^2$ | **$CO_2$production from aviation transport in the coastal area** (g * km * passenger) /km$^2$ | No. of passengers in Sardinia airports per year | Assaeroporti (https://assaeroporti.com/); Sardegna Mobilità - Bollettino Arrivi e Partenze (https://www.sardegnamobilita.it/bollettino-arrivi-e-partenze) | 2022 |
| | | | Average flight distance from Sardinia airports | FlightConnections (https://www.flightconnections.com/) | 2024 |
| | | | $CO_2$ per passenger km | Flight emission map (https://flightemissionmap.org/ | 2024 |
| | **$CO_2$production from maritime transport** /km$^2$ (g * km * passenger) (Sun et al. 2024) | **$CO_2$production from maritime transport in the coastal area** (g * km * passenger) | No. of passengers in Sardinian ports per year | Assoporti (https://www.assoporti.it/it/home/); Sardegna Mobilità - Bollettino Arrivi e Partenze (https://www.sardegnamobilita.it/bollettino-arrivi-e-partenze) | 2022 |
| | | | Average distance from Sardinia ports | Nautical Charts | 2024 |
| | | | $CO_2$ per passenger km | Department for Environment, Food & Rural Affairs - GOV.UK (https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs) | 2023 |

accommodation facilities during a given period (for example, a year or a month). This provides information on the accommodation capacity of a tourist destination, on the average length of stay of visitors and on the most attractive periods for tourism. The dashboard "Sardegna Turismo, Osservatorio del turismo, artigianato e commercio" is also the source of data on the number of beds per accommodation facility (both hotel and non-hotel), together with the Regional Register of Accommodation Facilities and Private Accommodation (Sardinia Region 2024a). The present research used the 2022 data to calculate the indicators included in the tourism domain.

The Report on urban waste management in Sardinia, published annually by the Sardinia Region ARPAS

(Agenzia Regionale per la Protezione dell'Ambiente della Sardegna - ARPAS 2022) and the National Waste Cadastre provided by the Institute for Environmental Protection and Research ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale - ISPRA, 2022) represents the main data source on the annual production of urban waste on a municipal scale.

The ARPAS Report and the ISPRA Waste Cadastre inform on the value of the total Production of Urban Waste per municipality, expressed in tons per year (t/year), and on the value of the production per tourist, expressed in kilograms per inhabitant per year (kg/inhabitant/year). The highest value of urban waste production per tourist is recorded in municipalities characterized by a high number of arrivals and stays. The data related to water consumption (mc) and energy consumption (KWh) per municipality, provided by Abbanoa Spa and Enel Energia respectively, are not open access data and a recent update is in progress.

The following data sources were used in order to compile the $CO_2$ production from aviation and maritime transport:

- Assaeroporti (https://assaeroporti.com/) and Assoporti (https://www.assoporti.it/it/home/) which provide the number of passengers in Italian airports and ports respectively.
- Sardegna Mobilità - Bollettino Arrivi e Partenze (https://www.sardegnamobilita.it/bollettino-arrivi-e-partenze) which provides the number of passengers (arrivals and departures) in Sardinian airports and ports.
- Flight emission map (https://flightemissionmap.org/), used to estimate $CO_2$ emissions per passenger, which the study assumes to be 127 g $CO_2$ per passenger km.
- FlightConnections (https://www.flightconnections.com/), used to define the average flight distance from Sardinia airports to the main destinations, which the study assumes to be approximately 1,000 km.
- Nautical charts are used to define the average distance from Sardinia ports (in maritime miles) to the main destinations, which the study assumes to be approximately 220 miles, which corresponds to 354 km.
- Department of Energy, Food and Rural Affairs (https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs), used to estimate the basic $CO_2$ emissions per passenger without a car, which the study assumes to be 19 g $CO_2$ per passenger km.

## Results

This study applies the proposed method to Sardinia. More precisely, tourism density, tourism intensity and accommodation density are the KPIs related to the tourism domain/data; waste production per tourist (WPT) and $CO_2$ emission are those related to the environmental domain/data. KPIs have been analysed and represented through spatial autocorrelation techniques.

With reference to the tourism KPIs, similarities can be observed in the application of the LISA method (Fig. 6). Indeed, high values of the data (tourism density, tourism intensity, accommodation density) and autocorrelation are found in coastal municipalities located in the North, Northeast, East, and Southeast. On the contrary, most municipalities located in the inner areas of the region are characterized by low values of the data and low autocorrelation. Close to coastal areas, some municipalities present lower values of the data and high autocorrelation, demonstrating that the hinterland municipalities respond to a portion of the coastal tourist demand.

The Western side of Sardinia exhibits insignificant data values and autocorrelation. Therefore, it can be inferred that there are no phenomena attributable to overtourism. On the contrary, the northern and southeastern parts show potential for overtourism as they present high values of all three KPIs and high autocorrelation. In the eastern side, although there are municipalities with high values of tourism density and accommodation density and high autocorrelation, the value and autocorrelation of the tourism intensity data appear not to be significant. This means that the potential overtourism phenomenon is less relevant compared to the Northern and Southeastern sides. The GIS representation shows the relationship between the KPIs, and the length of the coastline related to each municipality. The potential phenomenon of overtourism occurs in the north-east, east, south, and, to a lesser extent, in the west.

In the northern part, the high extension of the coastline allows for a greater tourist distribution, and, consequently, lower values of the data analyzed with the LISA method. In the southern part, some centralities emerge. Tourism intensity records high values in the municipality of Castiadas, in the south-east, where the number of tourists is very high compared to the length of the coast. Accommodation density records high values in the municipality of Pula, in the South-West, where the number of beds is very high compared to the length of the coast, and a significant part of the offer is guaranteed by big luxury hotels. The municipalities of Orosei and Dorgali, on the central-eastern side, present the highest values of tourism and accommodation density compared to the rest of the eastern side.

The GIS representation confirms the low significance of the tourism domain/data on the western side. The

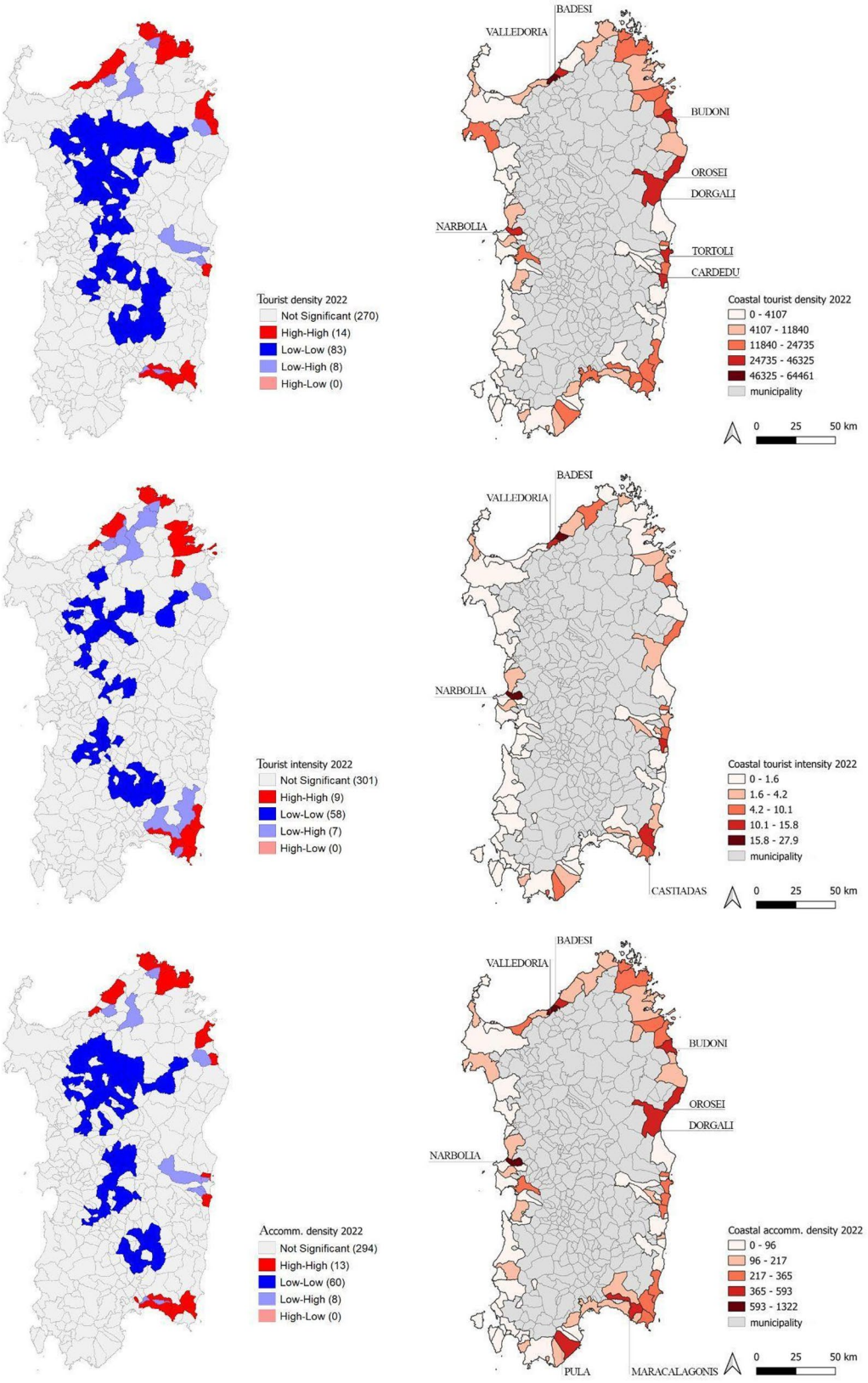



**Fig. 6** Spatial autocorrelation (on the left) and geospatial representation (on the right) of tourist density, accommodation density (beds/km$^2$) and tourist intensity (presences/population). Authors: G. Balletto and M. Ladu.

municipality of Narbolia, in the central-western part, is the only one that emerges with significant values of tourism intensity due to the limited length of its coast.

Potential overtourism is primarily observed in those areas close to Sardinian ports and airports. These areas can be defined as "airport/port regions", identified with 1-hour isochrones by private car. According to the Italian National Airports Plan (Piano Nazionale degli Aeroporti) 2022 (ENAC 2022), 80% of the Italian population can reach the nearest airport within 1 h from their municipality, while only 26% of residents can access it within the same timeframe using public transport. Public transport travel times are competitive with private cars only in metropolitan areas.

Furthermore, the potential overtourism depends on air and maritime transport supply. In fact, no significant KPIs related to the tourism domain/data have been recorded in the Alghero airport region, due to a more limited flight offer at the same airport. This is also in line with the following indices calculated by the Italian National Airports Plan 2022 (Fig. 8):

- Local Connectivity Index: 0.3 (AHO); 0.55 (CAG); 0.33 (OLB).
- Regional Accessibility Index (%): 0.22 (AHO); 0.54 (CAG); 0.21 (OLB).

As regards the KPIs related to the environmental domain, the waste production per tourist (WPT) records very high values in coastal areas, in the north and south, with reference to the southeastern part, and significant elements along the eastern coast (Fig. 7).

The highest WPT values are recorded in tourist destinations within the airport/port regions of Cagliari and Olbia. The representation of autocorrelation highlights the presence of two clusters: the northern one, shaped around the city of Olbia (with peaks in the municipality of Aglientu, up to Stintino), with High-High and Low-High values; and the southeastern one, shaped around Villasimius, with High-High and Low-High values. This condition is representative of the tourism supply system that is consolidating around the two main tourist destinations. The western coast is not significant, except for two isolated High-Low episodes, which represent high WPT values and low spatial autocorrelation. This condition highlights the low interest of the destinations. The inner areas are characterized by Low-Low values, demonstrating a generally lower tourist attractiveness and a governance capable of generating clusters.

Within the KPIs of the environmental domain/data, the study also evaluated $CO_2$ emissions produced by air and maritime traffic, which represent the only transportation systems allowed for movements to and from Sardinia (Fig. 8). Ports and airports may be considered the main gateways of the Island, exposed to significant emission: here, the $CO_2$ emission recorded depends on the number of passengers. As a matter of fact, Cagliari airport, with over 4 million passengers in 2022, is the first airport for $CO_2$ emissions, equal to 557.37 Gg. At the same time, the

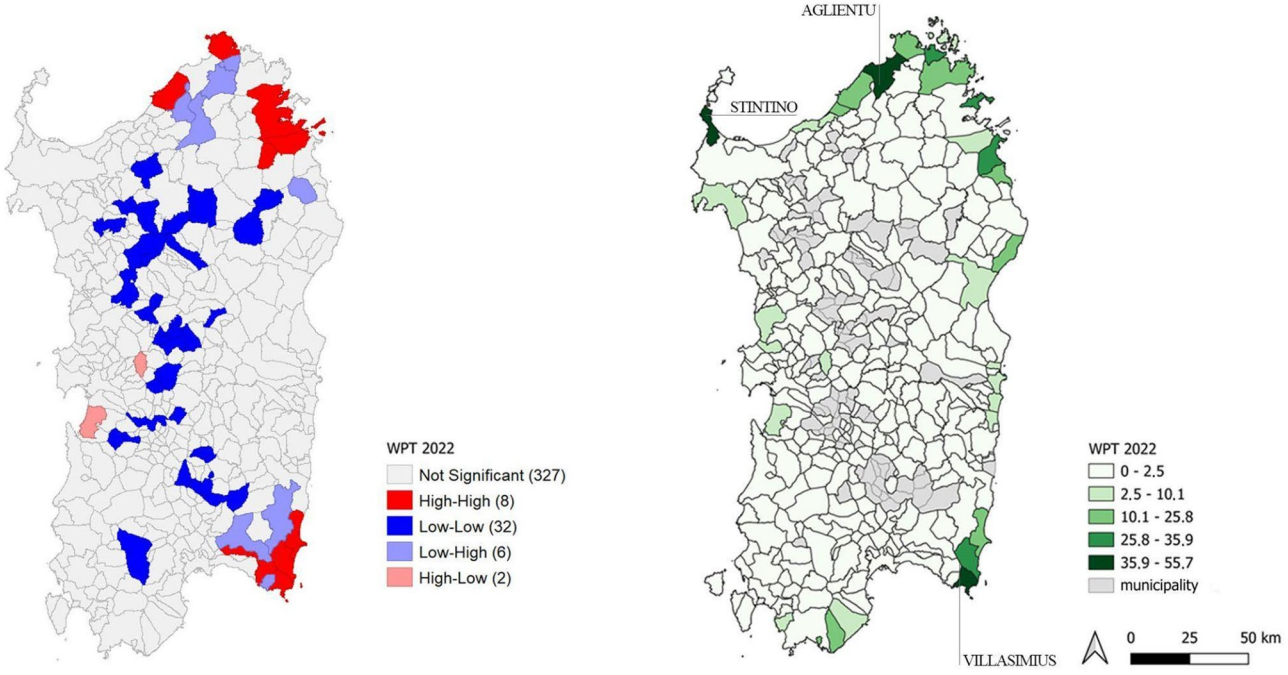
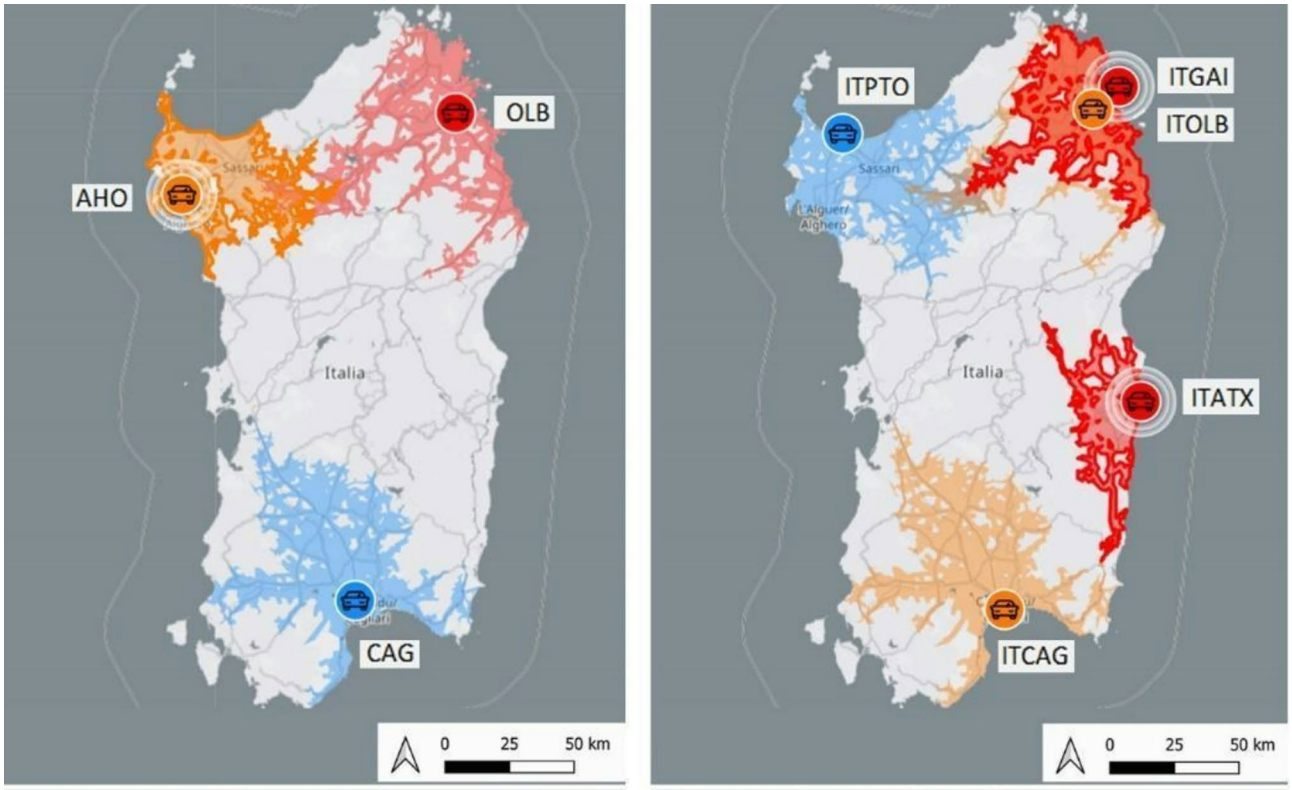



**Fig. 7** Spatial autocorrelation (on the left) and geospatial representation (on the right) of the Waste Production per Tourist (WPT). Authors: G. Balletto and M. Ladu




| Airport_Code | Total arrivals and departures_ passengers (2022) | CO2 aviation and maritime transport (Gg) |
|---|---|---|
| CAG | 4.388.742 | 557,37 |
| OLB | 3.128.592 | 397,33 |
| AHO | 1.526.078 | 193,81 |

| Port_Code | Total arrivals and departures_ passengers (2022) | CO2 aviation and maritime transport (Gg) |
|---|---|---|
| ITCAG | 204,114 | 1.37 |
| ITOLB | 2,909,306 | 19.57 |
| ITGAI | 580,350 | 3.90 |
| ITPTO | 1,099,252 | 7.39 |
| ITATX | 23,326 | 0.16 |

**Fig. 8** Airport regions (on the left) and port regions (on the right). $CO_2$ emissions from air and maritime transport. Authors: G. Balletto and M. Ladu

port of Olbia, with over 2 million passengers, is the first port for $CO_2$ emissions, equal to 19.57 Gg.

## Discussion and conclusions

According to the literature review that led to defining a conceptualization of potential risks of overtourism in tourism destinations, the study delved into the implications of tourism on islands focusing on the check step of the Deming Cycle that has been successfully adapted to define a methodology based on a set of KPIs specific to island regions and related geospatial representation and spatial autocorrelation to identify clusters and outliers.

The specific individual KPIs encompasses several sets of indicators proposed by the literature review, considering the two domains of tourism and environment to be applied in several administrative spatial dimensions (municipality, province, metropolitan city or region) related to the island contexts and coastal areas. In particular, the tourism domain involves tourist density and intensity, accommodation density and gross use of hotel and non-hotel facilities), tourist load and accommodation load; the environment domain concerns waste production, water consumption, energy consumption, and $CO_2$ production from aviation and maritime transport.

The spatial analysis of KPIs enables the identification of areas most vulnerable to overtourism, supporting the development of renewed tourism management policies.

In this sense, the manuscript enriches the theoretical and scientific context, linking the study to broader theories on sustainable tourism and destination management, introducing the possibility of comparison with other Mediterranean islands.

When applied to the case study of the island region of Sardinia, using available open data KPIs, the method

reveals distinct spatial patterns for each specific KPI, highlighting variations in tourism pressure within the Sardinian Island context.

The study clearly indicates a concentration of tourism activities along the Sardinian coast, particularly in the north, northeast, east, and southeast. These areas exhibit higher values for tourism density, intensity, and accommodation density. The spatial autocorrelation maps highlight the clustering of high tourism values in specific coastal areas. This suggests that tourism development in these areas is not isolated but rather part of a larger spatial pattern.

Conversely, inner areas of Sardinia generally exhibit lower tourism values and less or no significant spatial autocorrelation, indicating a less intense tourism presence, confirming that tourism in Sardinia remains primarily coastal and beach oriented. The eastern coast shows some high autocorrelation values for tourism density and accommodation density, while tourism intensity is relatively lower. This suggests that although there is a significant tourism presence, the duration of tourist stays may be shorter. The analysis of KPIs in relation to coastline length demonstrates that areas with longer coastlines, such as the northern part, can accommodate a larger number of tourists without reaching the same density levels as areas with shorter coastlines.

Finally, regarding the environmental aspect, the study evaluated the waste production per tourist (WPT), which, in addition to confirming the attractiveness of coastal areas, deserves particular attention because it is significantly manifested in areas subject to environmental protection constraints such as La Maddalena Archipelago National Park, the Asinara National Park, the Tavolara and Punta Coda Cavallo Marine Protected Area in the north, and the Capo Carbonara Marine Protected Area in south east. Regarding environmental aspects, the study highlights the role of airports and ports in shaping tourism patterns and the consequent $CO_2$ emissions produced by air and sea transport to and from the islands. Airport and port regions, corresponding to 1-hour car isochrones (Fig. 8), show higher tourism activity, except for Alghero. Research results suggest that although Sardinia does not seem to suffer from widespread overtourism, some coastal areas, particularly the North, Northeast, South, and Southeast coasts, are more vulnerable. These areas should benefit from further targeted interventions to manage tourism growth and mitigate its potential negative impacts.

Although the north-east and south-east side, characterized by the presence of marine protected areas, have recently initiated policies to limit access to the beaches (approximately 20 among the most unique beaches), the growth of tourist flows requires a renewed approach, developing a regional spatial plan that identifies the areas risk of overtourism to promote sustainable tourism practices, including the reduction of waste production, energy efficiency, the protection of natural and cultural resources and a more coherent management of the tourist tax. The risk of overtourism affects all coastal municipalities (except for the southwestern coast) such as Stintinu, Badesi, Aglientu and Olbia in the north, the cluster of Budoni, Orosei, Dorgali, and Tortolì on the eastern coast, and the areas within the Gulf of Cagliari, from Pula to Castiadas.

The tourist tax in Italy has been constantly growing and has exceeded 700 million euros in 2023, marking an increase of 9.5% compared to 2022. This increase is due to the increase in the number of tourists and the number of municipalities that introduced the tax. Despite the existence of legislation that limits the use of tourist tax funds to specific interventions in the tourism sector, a strategic vision and detailed and transparent reporting are still lacking (Menegus 2025).

Future developments concern the integration and definition of specific weight for the KPIs coming from different sources amplifying the multidisciplinary approach to allow the identification of significant correlations between tourism, economic development, the quality of life, the conservation of ecosystems and the impact on climate crisis. Moreover, the application of the methodological approach will evolve towards the DPSIR model, with reference to the "Impact and Responses" phases, to develop future scenarios to ensure long-term sustainability of tourism and propose common best practices for island tourism destinations.

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**Author contributions**
Conceptualization, methodology, formal analysis and investigation, G. B. and M. L.; validation, resources, data curation, writing—original draft preparation, writing—review and editing and supervision, all authors. In particular, Introduction was written by S. B.; Conceptualization of overtourism was written by G. B. and M. L.; Overtourism in islands was written by M.A.; Methodology was written by G. B. and M. L.; LISA Spatial Autocorrelation was written by G. B.; Study area and Data was written by M. L.; Results was written by G. B. and M. L.; Discussion and Conclusions was written by G. B. All authors reviewed the manuscript.

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**Data availability**
No datasets were generated or analysed during the current study.

## Declarations

**Competing interests**
The authors declare no competing interests.

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