Università degli studi di Milano-Bicocca

Data Science Lab for Smart Cities

Final Essay

Mobility in Northern Sardinia

Author:
Fabrizio Cominetti - 882737 -
f.cominetti1@campus.unimib.com

September 3, 2023

Abstract

In this project, we're diving into how people move around in the northern part of Sardinia, starting from the arrivals by airports and ports and focusing mainly on public transport stops to reach key facilities. Transportation is a big deal for making places thrive, and the goal is to understand this and find ways to improve it. To analyze the situation, several indicators are calculated, accompanied by data visualizations. As for airports and ports, the project aims to examine the flows both on a seasonal basis, differentiating by the airport of arrival and departure, and by checking the number of domestic and foreign tourists. The analysis then focuses in particular on the situation of public transportation for tourists, analyzing their current conditions and the possibility of reaching popular destinations such as beaches, as well as for residents and connections to more populated areas. In the end, some suggestions to policy makers are provided.

Contents

1 Problem Description and Indicators

As urbanization has continued to grow at an unprecedented rate in recent years, the idea of a "Smart City" has acquired a lot of popularity. In order to improve operational effectiveness, foster sustainable development, and improve the quality of life for its citizens, a smart city makes use of digital technology, data analytics, and intelligent infrastructure. Because mobility plays a crucial role in our everyday lives, it is essential to the success of any smart city. Humans spend a lot of time, money, and energy traveling, therefore redesigning mobility is one of the most important challenges of our time. It has become crucial to analyze and comprehend human movements since mobility patterns are intricately linked to significant socioeconomic challenges. As populations grow, cities face increasing pressure on their transportation systems, leading to congestion, pollution, and decreased quality of life. Mobility within a city encompasses the movement of people and goods, making it a vital aspect of urban living. The transportation industry has a relevant impact on gas emissions and on the environment. Instead, to reduce emissions, save energy, and improve air quality, smart cities encourage sustainable mobility, such as electric public transit, bicycle infrastructure, and pedestrian-friendly urban planning. Sustainable mobility is a critical component of smart city efforts to minimize emissions since urban transportation accounts for 25% of all energy-related CO2 emissions globally [9]. In addition, efficient transportation networks reduce congestion, save time, and boost productivity, smart cities use data analytics and real-time monitoring to optimize public transportation reliability. Well-connected transportation systems are a key factor for attracting investment and talent, contributing to city prosperity, and urban accessibility is vital for social inclusion and equal opportunities [5] [8]. Mobility is a significant challenge and opportunity in the development of smart cities, and it requires innovative, sustainable, and efficient solutions: achieving mobility goals is essential for improving residents' - but not only - quality of life and advancing smart city objectives related to sustainability, efficiency, and inclusivity. Another critical point revolves around cars. Cars come with massive inefficiencies due to their skewed space requirements and usage patterns, and when roads are not - for geographical characteristics in this case - so developed, efficient public transports become even more required. Empirical evidence and mathematical/simulation models, in fact, show that cities as (car-centric) transport mono-cultures are not sustainable. The biggest question in urban transport is how to reverse car dependency, so how to replace unsustainable modes of transport and to prioritize sustainable ones. Active travel such as walking and cycling has the highest societal benefits, but when it comes to regions such as the one object of this study, it is not always a feasible choice. It is possible, however, to overcome transportation mono-cultures with a focus on more multimodal transport, that is is the combination of multiple transport modes promising all benefits while avoiding their weaknesses. Smart mobility constitutes a recurring component in smart city discourses, and bringing to light and highlighting the problems and flaws of a mobility system in a specific location is the first step to understanding where improvements are needed and where to make positive changes for everyone.

1.1 Mobility in Northern Sardinia

The theme of mobility in Northern Sardinia, particularly in the province of Sassari, is a relevant issue with significant implications for the province and its inhabitants. One of

the core issues is the inadequacy of the public transport infrastructure in the region: this includes insufficient bus and train services, outdated infrastructure, and limited coverage, especially in rural areas, and it leads to longer commute times, inconvenience, and a heavy reliance on private vehicles. The lack of efficient public transport connections to key facilities such as airports and beaches is a significant concern. Tourists, residents, and businesses depend on these facilities. In addition, many tourists choose the airplane to travel to Sardinia. Inevitably, this option does not provide them with a car, which is often necessary to move around the island. Precisely for this reason, after studying the passenger flow in airports, it becomes necessary to assess the current transportation situation in Sardinia. The over-reliance on private vehicles due to poor public transportation options contributes to increase traffic congestion, pollution, and a higher carbon footprint. This not only harms the environment but also affects the overall quality of life in the region. This can also lead to road safety concerns, and tourism, a significant economic driver in many coastal regions, can suffer due to poor accessibility to beaches and other attractions. The lack of efficient transportation options can deter tourists from visiting the region. Limited public transportation options can disproportionately affect vulnerable populations, such as low-income individuals who may not have access to private vehicles, exacerbating social inequalities. But also, inhabitants of municipalities not directly connected to key facilities such as beaches and airports/ports. Near strategic places like beaches, parking spots are not always available in large quantities, and it causes inefficiency for tourists and residents. Also for this reason, park tickets are increasing in price, leading tourists to search for alternatives to reach the beaches and facilities of choice.

Analyzing the current status of public transport stops in the municipalities of the province of Sassari is crucial to identify gaps and areas for improvement. This includes assessing the location of stops, and evaluating whether they are strategically located to serve the needs of the population. In conclusion, the impact of the mobility issue on the environment, economy, social fairness, and general quality of life in Northern Sardinia, particularly in the province of Sassari, makes it a significant issue. For the city's and its residents' sustainable growth and well-being, it is crucial to address these problems through enhancing public transportation infrastructure, connectivity to important services, and finding gaps in the current system.

1.2 Indicators

To measure the problem pointed out and its impacts on citizens and tourists, various indicators were developed and analyzed, starting from the exploration of arrival of people in the region to the analysis of the situation of the public transport stops, and the access of tourists and residents to key facilities.

- *Passenger Flows*
  A series of indicators to give an overall view of the passenger flow and airport activity. The analysis take into account departures, arrivals, but also net passenger flow for the airports (Olbia and Alghero) and the port (Olbia).

- *Seasonal Variation*
  An indicator to analyze if passenger flow varies based on seasons. This can help in planning resources and services accordingly.

- *Domestic vs. International Passengers*

Analyze the proportion of passengers traveling domestically and internationally. This provides insights into the tourism and business travel patterns.

- *Transportation Infrastructure Connectivity*
  This indicator measures the accessibility of airports through various public transport modes. It assesses how well airports are connected to their surrounding areas by public transports.

- *Bus Stop Density*
  The number of bus stops per unit area in different municipalities. This indicator can help identify areas with higher - and lower - public transportation accessibility. Evaluate also how well the entire region is covered by the public transport system, including areas that might not be close to the airport but still contribute to overall connectivity.

- *Bus Stop Location in Relation to Population Density*
  Overlay the bus stop locations with population density data. Analyze if bus stops are strategically placed in areas with higher population concentrations.

- *Sea Accessibility Index*
  Given that Sardinia has access to the sea, we can calculate an accessibility score to measure how well bus stops serve this destinations, so the proximity of bus stops to beaches.

1.3 Ethical and Social Implications

Addressing the mobility situation in Northern Sardinia within the context of Smart Cities should prioritize ethical considerations such as privacy, equity, inclusivity, sustainability, and community engagement. This analysis - that focuses on tourism and tourists -, do not have to forget the consequences on residents. For instance, to increase the level and quality of public transports in the region, a common strategy lead to increase the price of tickets, that can influence also the residents; in this specific case, coupons on annual passes can mitigate this issue. Also, the beaches in this region are full of tourists in the summer, and this can additionally lead to over-tourism in certain places. On the other hand, exploiting gaps and make more beaches accessible can offer the chance to find alternatives and to prevent people flows from concentrating in the same points. As we'll see below, the municipalities that are not populated by tourists, and that are located in the center of the region, face difficulties because, compared to other areas, the residents do not earn from certain seasons and the tourism phenomenon. Therefore, to address the issues of transportation we cannot be only driven by accessibility to tourist destinations. In conclusion, preserving natural coastal areas and minimizing environmental degradation caused by over-tourism and transportation should be a critical point for every organization and entity in the area.

2 Data Analytics, Optimization and Policy Suggestions

In this section, the datasets - identified and selected as relevant for studying the topic - will be introduced, along with a brief description of their themes and contents as well as links to the resources to access them. After a phase of data cleaning and exploration, the indicators presented in the first part of this work will be computed, accompanied by relevant visualizations. This will be followed by a discussion of the main results, suggestions for potential new policies or optimizations based on the data analysis to address the problem.

2.1 Data

Sardinia, officially known as the "Autonomous Region of Sardinia" (Regione Autonoma della Sardegna), is a distinctive region of Italy geographically characterized by its island status. It is the second-largest island in the Mediterranean Sea, after Sicily, and it is located to the west of the Italian mainland - separated from it by the Tyrrhenian Sea. Sardinia is divided into five provinces, each with its own unique characteristics and cultural heritage. These provinces, from north to south, are *Sassari, Nuoro, Oristano, Sud Sardegna, and Cagliari* [16]. Sardinia is renowned for its stunning coastline, which stretches for approximately 1,85 kilometers, and that are the driving force of tourism, the most relevant economic factor for the entire region. The interior of the island, however, is facing a difficult situation, particularly concerning demographic decline. The central areas often struggle to develop like the major cities, which are now the destination for many citizens. The generational turnover, in fact, is increasingly leading citizens to choose to move to more coastal and populated areas. It is estimated that, in the period between 2016 and 2021, 50 thousand of inhabitants chose to move from interior municipalities to Sardinia or other regions of Italy, but also to other European places [4]. The situation has also led to the introduction of some monetary and non-monetary bonuses by the government, aimed at encouraging the re-population of certain areas [3]. The province of Sassari, the main focus of this project, is located in Northern Sardinia, and it includes 474 thousands of inhabitants distributed across 92 municipalities, for a total extension of 7.701,76 (km^2) square kilometers [16]. This province contains a relevant number of beaches, two airports - one situated in the municipality of Olbia and the other in Alghero -, and one port - situated in Olbia.

To analyze the territorial characteristics of this province, the dataset provided by ISTAT [10] - Italian National Institute of Statistic - has been chosen, which contains various information regarding Italian regions, provinces, and municipalities. ISTAT offers geospatial data, and it provides the Italian administrative borders in vector format. The main directory downloaded, called 'Limiti01012023' contains four subfolders:

- **RipGeo01012023** - folder with boundary info about the macro-regions of Italy
- **Reg01012023** - folder with the regions of Italy
- **ProvCM01012023** - folder with the provinces of Italy
- **Com01012023** - folder with the municipalities of Italy

Analyzing the dataset related to provinces, filtered to include only the provinces of Sardinia, the presence of invalid geometries was observed for two out of the five provinces, including the province of Sassari. To address the issue, the points causing the problem were identified and extracted, and they were corrected using the buffer function. The buffer() function is a geometric operation commonly used in Geographic Information Systems (GIS) and spatial analysis. It essentially creates a buffer or a zone around a geometric shape, such as a point, line, or polygon, and it is used as a workaround to address certain types of invalid geometries. This operation can help fix issues like self-intersections, overlapping polygons, or other geometric problems that might make a geometry invalid according to the rules of spatial data. Subsequently, when analyzing the dataset related to the municipalities in the province of Sassari, it was also found that there were invalid geometries for two municipalities, specifically the municipalities of 'La Maddalena' and 'Calasetta.' The procedure for addressing the issue was the same as described above, and this allowed for an initial visualization of the map of municipalities within the province.

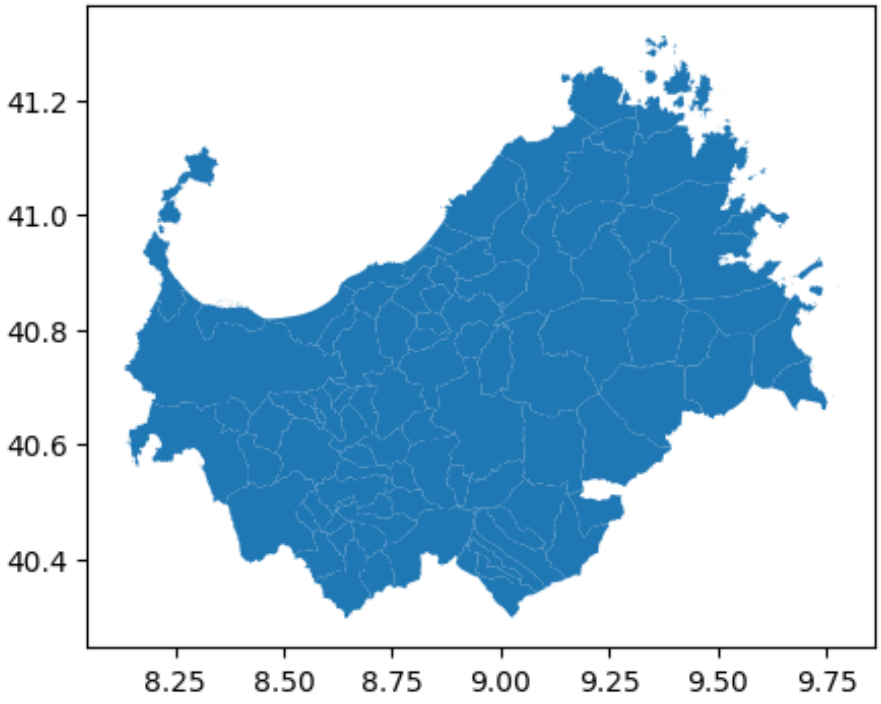

Figure 1: Municipalities - Sassari

As we can observe from the visualization, a relevant number of municipalities is connected to the coast, and some municipalities are broader - in extensions - compared to others.

Many of the datasets that will be used in the data analytics section, and that will be briefly introduced in this paragraph, are open-sourced by the Sardinia region [15]. For each dataset, the main steps of data cleaning and data pre-processing were applied, from handling NaNs to convert columns to the right datatypes.

The first dataset to take into account regards a bulletin of arrivals and departures for airports and ports in Sardinia. It contains daily data on arrivals and departures from the ports and airports of Sardinia [13]. The data source is the PMIS system of the General Command of the Harbor Masters for port-related data and airport management companies for airport-related data. These are the columns:

- **Data**: date in yyyy-mm-dd format.
- **Porto/Aeroporto**: indicates whether the row refers to a port or an airport.
- **Nome**: the name of the port or airport.
- **Arrivi**: number of arriving passengers.
- **Partenze**: number of departing passengers.
- **Totale**: the sum of arrivals and departures.

From this dataset, only the values containing data about the airports of Olbia and Alghero and the port of Olbia were extracted.

A second dataset contains the passenger flows at Sardinia's airports [14]. As the metadata explain, The dataset is obtained from the processing of scale records transmitted to the Sardinia Region by the airport management companies of Alghero, Cagliari, and Olbia. The dataset contains the number of passengers arriving and departing from the airports in Sardinia, aggregated by the Sardinian airport of origin/destination, the geographical 'zone' to which the arriving/departing airport belongs, and the 'period' of activity. A 'zone' is, in the case of domestic traffic, the combination of several Italian regions; in the case of international traffic, it is the combination of several foreign states as represented in the 'zone' table. The statistics only concern passengers transported by scheduled and charter flights; other types of traffic, such as postal, air taxis, and general aviation, are not taken into consideration. These are the columns:

- **Aeroporto**: the name of the airport.
- **Anno**: year of reference.
- **Periodo**: the period of reference, divided in various sections but not considered for the analysis.
- **Zona**: code of the zone.
- **Pass_Arrivo**: number of arriving passengers.
- **Pass_Partenza**: number of departing passengers.

This dataset is directly related to another dataset, containing info about the origin and destination zone of passengers. These are the columns:

- **Paese**: name of the state.
- **ISO2**: abbreviated name of the state.
- **regione**: region name for Italy, * for other nations.
- **ID_zona**: id of the zone, related to the 'Zona' column of the previous dataset.

Next, a dataset containing info about public transports in Sardinia is considered [12]. The dataset is composed by these columns:

- **stop_id**: unique id of the stop.

- **stop_code**: numeric code of the stop.
- **stop_name**: complete name of the stop.
- **stop_desc**: description of the stop.
- **stop_lat**: latitude of the stop.
- **stop_lon**: longitude of the stop.
- **stop_comune**: municipality name of the stop.
- **wheelchair_boarding**: contains info about the accessibility for people with wheelchair.
- **stop_type**: type of the stop, if bus, train, or other.

In this case, only the stops contained in the municipalities of Sassari were filtered, and some columns, such as stop_code, stop_desc, and wheelchair_boarding, were dropped because of lack of information.

Another dataset was downloaded from ISTAT, this time regarding resident population in Sardinia. The dataset, manually scraped to include only the municipalities of interest and updated for 2023, contains only two columns:

- **Comune**: name of the municipality.
- **Popolazione**: number of the resident population.

The last dataset regards beach systems of Sardinia. As described in its metadata, the original dataset [7] contains dune fields and beach systems. Precisely, polygonal elements representing areas characterized by coastal morphologies. "These elements belong to those natural landscape typologies identified in the coastal strip and transitional zone, categorized and protected by the Landscape Plan (Article 17, paragraph 3, letters b and c of the N.T.A. PPR)". These are the columns:

- **idFeature**: unique id.
- **tipoElCod**: 1 for dune fields, 6 for beach systems.
- **tipoElDesc**: complete name of the type, 'Campi dunari' or 'Sistemi di spiaggia'.
- **geometry**: polygon info.

After filtering out the dune fields, the dataset was saved like the others in a suitable format for further analysis.

In addition to all of this datasets, a simple datasets was created, containing only the latitude and longitude for the two airports of Olbia and Alghero.

2.2 Data Analytics

The first contact between tourists and the Northern Sardinia region takes place at ports and airports. Many tourists choose the airplane to travel to Sardinia. Inevitably, this option does not provide them with a car, which is often necessary to move around the island. Precisely for this reason, after studying the passenger flow in airports and ports, it becomes necessary to assess the current transportation situation in Sardinia. Due to the unsatisfactory state of public transportation and the difficulty of reaching certain areas, also due to the characteristics of the natural landscape, the choice to rent a car is often mandatory. The prices for acquiring a car, especially for tourists who have no alternative to flying to the island, are steadily increasing and risk excluding more and more groups of people from the possibility of reaching certain areas [2] [18]. In recent years, the business of car sharing and car renting has touched levels never reached before. Another point to consider in the subsequent analysis is that the geographical layout also plays a significant role; in fact, many roads are not suitable for transportation vehicles.

Passenger Arrival and Departure Counts

The data available for analyzing passenger flows at the Olbia and Alghero airports span from the beginning of 2019 to mid-2023. To compare complete years, the analysis exclude the first months of 2023, considering data up to the end of 2022. First, the data were grouped by airport and total count, without distinguishing by year. Here are the results:

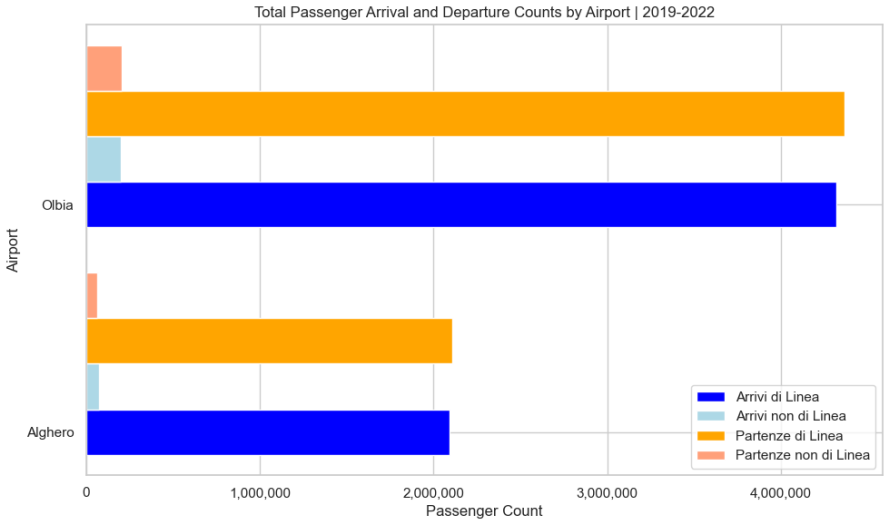

Figure 2: Passenger Arrival and Departure Counts by Airport

As we can observe, Olbia Airport deals with a significantly higher number of passenger traffic. This applies to both regular flights and non-regular flights. Next, without distinguishing between the two airports, we chose to display the passenger flow in the airports of northern Sardinia by year:

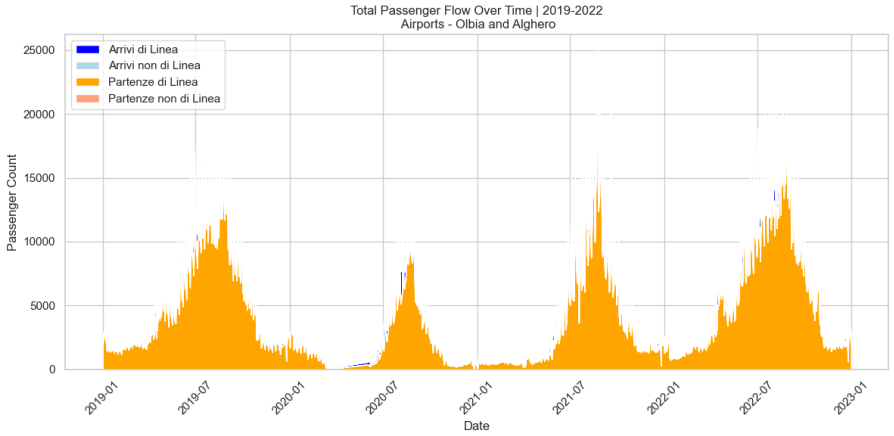

Figure 3: Passenger Flow Over Time - Airports

As we can see, the years 2020 and 2021 had a lower passenger flow. The same analysis has been conducted for the Olbia's port in Northern Sardinia, and it leads to similar conclusions:

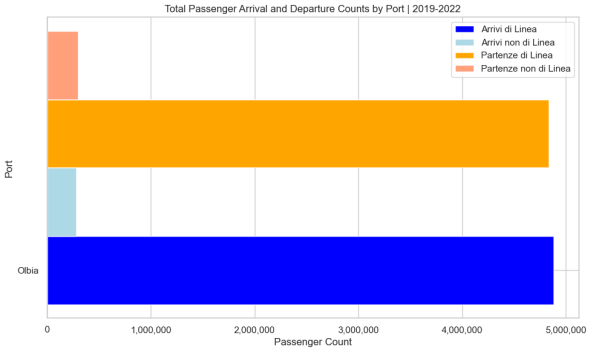

Figure 4: Passenger Arrival and Departure Counts by Port

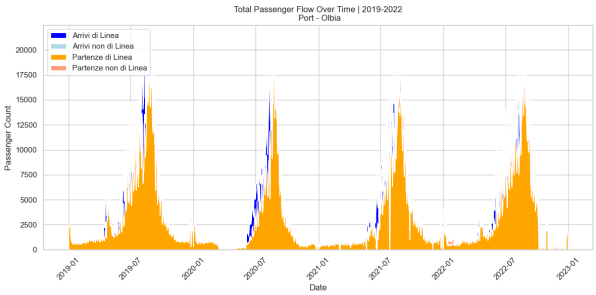

Figure 5: Passenger Flow Over Time - Ports

Seasonal Variation

As stated earlier, Sardinia is a region that thrives on tourism, so it is interesting to observe passenger flows during different seasons of the year to check if the flows are consistent throughout the year or if they concentrate, as expected, in certain periods. Furthermore, since the analysis aims to focus on tourists who want and can choose not to have a car, at least initially, we will concentrate on airport data. The four seasons - spring, summer, fall, and winter - can help us define and differentiate from seasonal variations. In this case, the seasonal variation corresponds to the sum of passenger - regular and non-regular - in each season. With a pivot table and an heatmap, we can observe the total arrivals, first in both airports, then for each one:

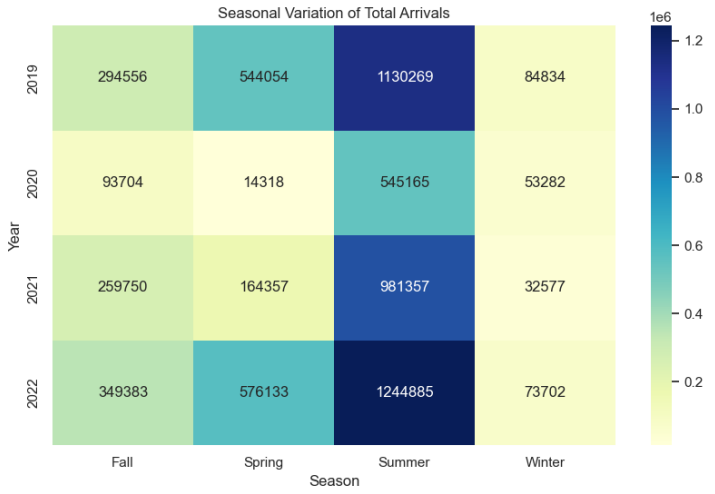

Figure 6: Seasonal Variation of Total Arrivals

Season	Total Arrivals	Total Departures
Fall	249348.25	291089.500
Spring	324715.50	285936.500
Summer	975419.00	985070.250
Winter	61098.75	62593.375

Figure 7: Seasonal Passenger Data

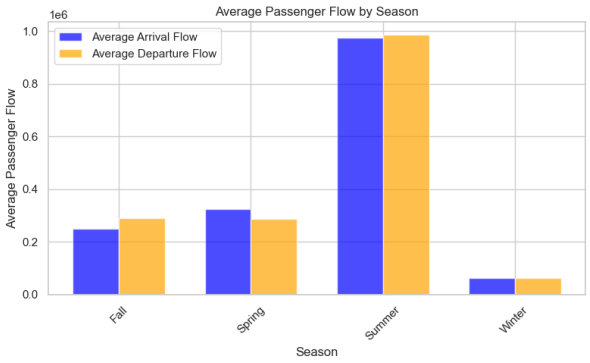

Figure 8: Average Passenger Flow by Season

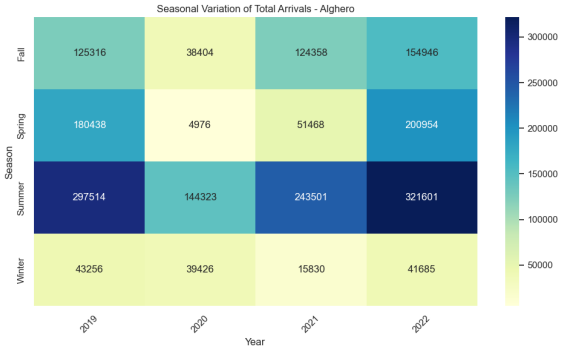

Figure 9: Seasonal Variation of Total Arrivals - Alghero

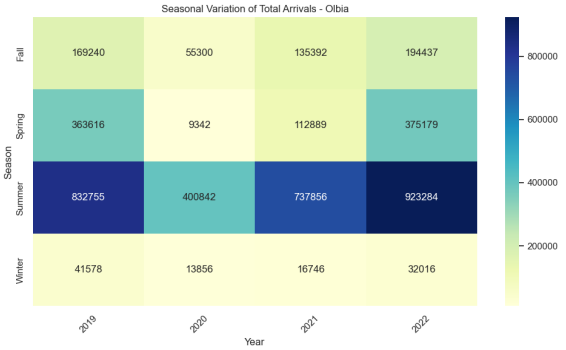

Figure 10: Seasonal Variation of Total Arrivals - Olbia

Below, we can observe a simpler visualization that definitively clarifies the quantity of passengers at the airports for each season.

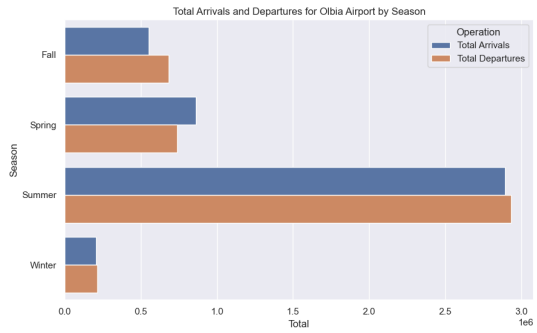

Figure 11: Total Arrivals and Departures for Olbia Airport by Season

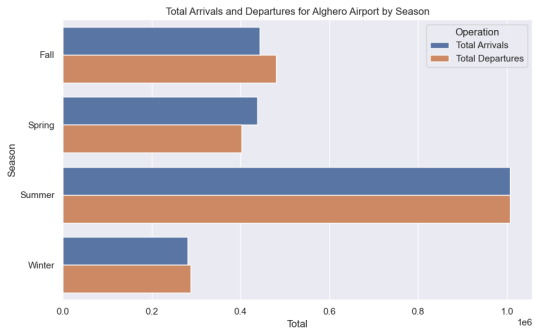

Figure 12: Total Arrivals and Departures for Alghero Airport by Season

To end this discussion, we can show the net flow, which is derived from the number of arrivals minus the number of departures from the airports:

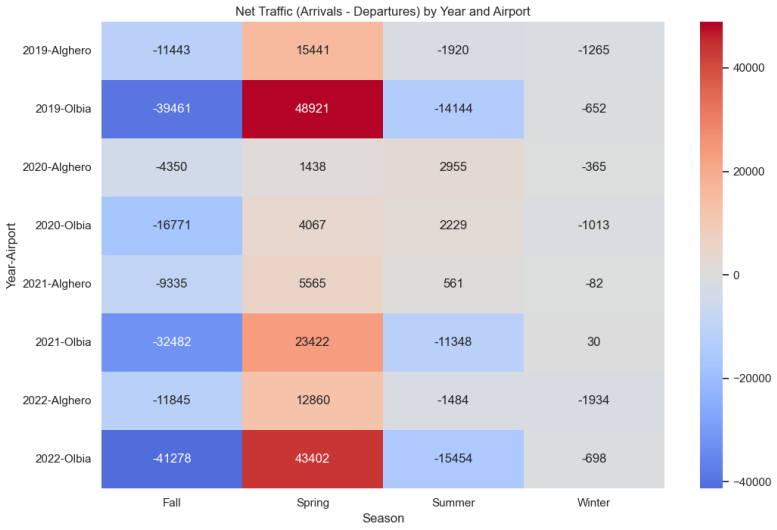

Figure 13: Net Traffic (Arrivals - Departures) by Year and Airport

Domestic vs. International Passengers

Sardinia enjoys great tourism and appreciation from Italian residents in other regions. For many, it is the first choice for vacations, but it also attracts a significant number of foreign tourists from various parts of Europe and the world. By analyzing the available data on arrivals and departures from the airports of Olbia and Alghero, along with the origins and/or destinations of passengers, we can quantify the impact of both Italian and foreign tourism on the region's overall tourism. Obviously, we need to take into account other types of movements, for instance for business reasons, and many other reasons apart from summer tourism.

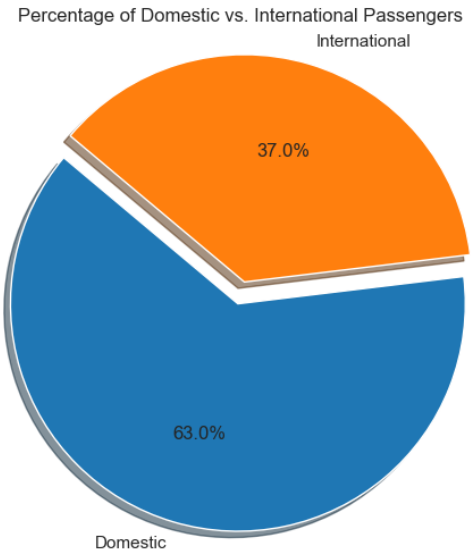

Figure 14: Percentage of Domestic vs. International Passengers

Transportation Infrastructure Connectivity

Now we can move on to another topic. As mentioned earlier, tourists who reach Sardinia by plane must face the current state of transportation, which we will investigate. First and foremost, we can observe the number of public transportation stops (green), of any kind, in the province of Sassari, along with the airports locations (blue):

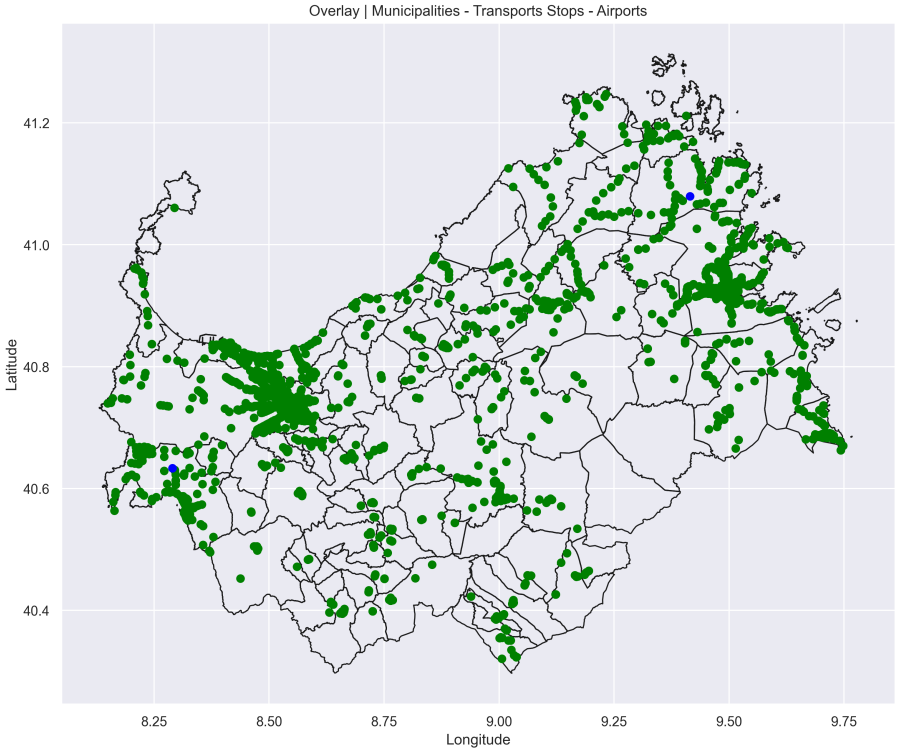

Figure 15: Overlay of Municipalities, Transports Stops, and Airports in Sassari

A first impression we can gather from the figure is certainly the concentration of stops in various areas and the absence in others. Furthermore, near the airports, the situation appears suitable and functional. Now we can delve deeper into the transport stops, dividing in the figure by stop type. In the dataset, in fact, we can distinguish between bus stops, metro stops, and train stops:

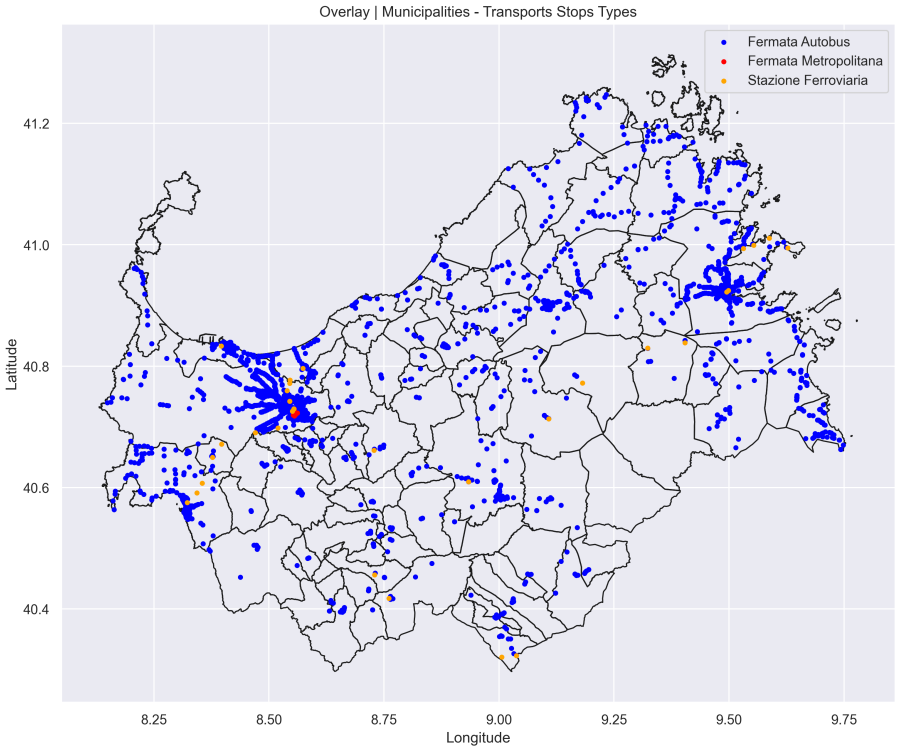

Figure 16: Overlay of Municipalities and Transports Stops Types in Sassari

We can observe how metro stops are only present in the municipality of Sassari, and train stops follow specific routes. The image also clearly highlights the prevalence of bus stops, the primary public transportation mode, in the province.

Now, for each stop, an accessibility score for each airport was calculated, considering the geodesic distance between each stop and the airport location. Then, an average accessibility score for each airport, based on the distances, has been calculated. To make the analysis more relevant, the stops were filtered considering only an x radius - in kilometers - for stops around each airport. In this case, the chosen radius corresponds to 5 kilometers. The average accessibility score in kilometers represents the average distance between the transport stops and the airport, it is a measure of how connected the airport is to the surrounding areas by public transportation. A lower value indicates better accessibility, meaning that the transport stops are, on average, closer to the airport. For instance, if the average accessibility score for Olbia Airport is 5 kilometers, it means that, on average, the transport stops in the dataset are about 5 kilometers away from Olbia Airport. Here are the results:

Location	Average Accessibility Score (kilometers)
Olbia	3.25
Alghero	3.19

Table 1: Average Accessibility Scores

This score assumes more relevance if we calculate the number of stops in the chosen radius:

Location	Radius (km)	Number of Stops
Olbia	5.0	28
Alghero	5.0	30
Olbia	2.5	7
Alghero	2.5	10

Table 2: Number of Stops within a Radius

Transport Stops Density

Let's now analyze the density of public transportation stops. We'll start with the number of stops for each municipality, so grouping the data by the municipality of the stop and then counting the number for each municipality. When filtering to observe the 'head' and 'tail' of the aggregated dataset, we can notice a certain disparity:

stop_comune	stop_count
SASSARI	843
OLBIA	492
ALGHERO	180
TEMPIO PAUSANIA	112
PORTO TORRES	103

(a) Head

stop_comune	stop_count
MONTELEONE ROCCA DORIA	1
SANTA MARIA COGHINAS	1
MUROS	2
PADRIA	2
ITTIREDDU	2

(b) Tail

Additionally, some municipalities were automatically excluded from the count as they don't even contain a single stop. The municipalities in question are five: *Alà dei Sardi, Buddusò, La Maddalena, Nughedu San Nicolò, Trinità d'Agultu e Vignola.*

Now, we can merge the population dataset with the stops data, and, after calculating the area of each municipality, we can calculate the bus stop density by dividing the number of stops by the corresponding municipality's area. Higher values of the 'bus_stop_density' columns corresponds to a higher number of bus stops, in relation to the resident population of each municipality.

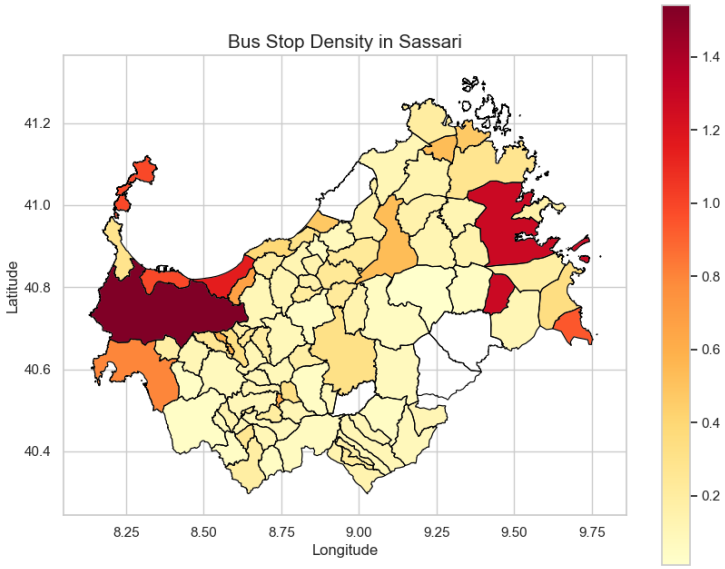

Figure 17: Bus Stop Density in Sassari

Bus Stop Location and Population Density

To enhance the previous analysis, we can compare the placement of bus stops location with the population density in each municipality. After calculating population density and the bus stop density, we can create an indicator score that take into account these two factors with the same weight, and then plot a map with the indicator:

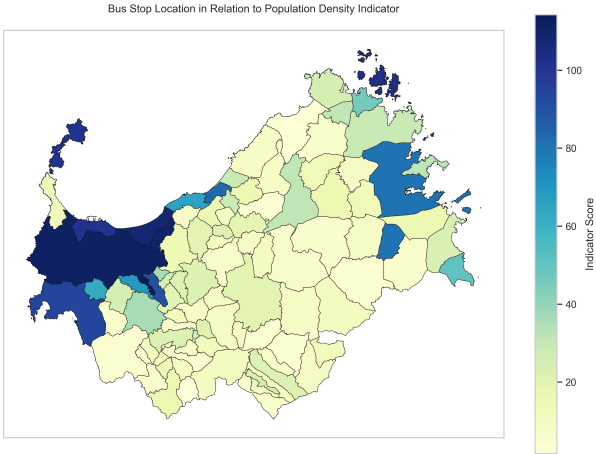

Figure 18: Bus Stop Location in Relation to Population Density - Indicator Score

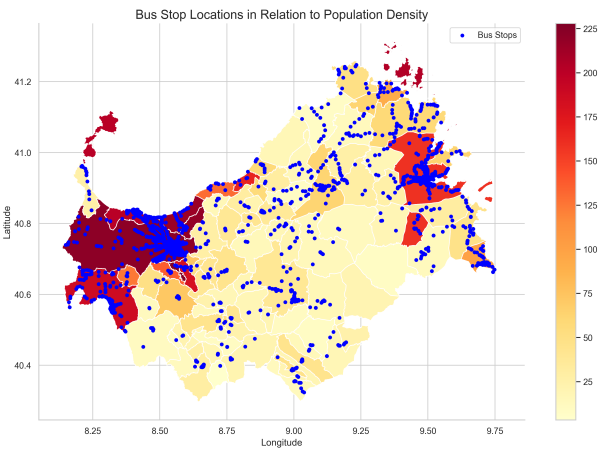

Figure 19: Bus Stop Locations in Relation to Population Density

The interpretation of the visualization on the left involves analyzing how well bus stops are strategically placed in relation to population density. Areas with a high population density and well-placed bus stops will likely have darker colors on the map, indicating a higher indicator score. On the other hand, areas with lower population density and less strategic bus stop placement will have lighter colors and lower scores. Darker colors on the map indicate higher indicator scores. This means that in these areas, the placement

of bus stops is considered more strategic in relation to population density. In other words, there's a higher likelihood that bus stops are conveniently situated in locations where they are accessible to a larger number of residents.

Sea Accessibility

To calculate the accessibility score of beaches in the province of Sassari, we first need to extract representative points for each beach. From this points, we can extract the latitude and longitude of the beaches, necessary to run distances for later analysis. To start, we can plot the beaches (green) along with the map of bus density stops:

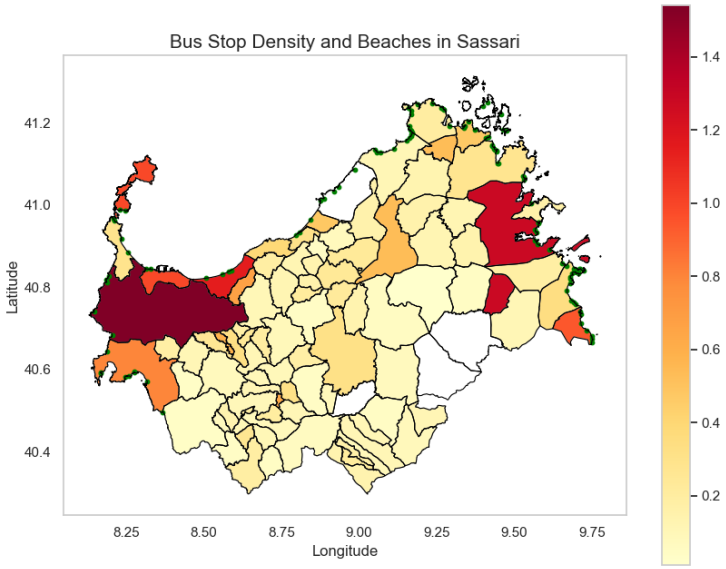

Figure 20: Bus Stop Density and Beaches in Sassari

We can immediately observe the lack of bus stops in critical places. We can continue by calculating the proximity of bus stops for each beach, as well as the nearest bus stop and the concentration for each beach. After re-projecting the geometry data to the correct configuration, we can calculate the nearest distance for the stop for each beach, and then normalize the distance score between 0 and 1. After all of this, we can calculate the average accessibility score for all beaches:

Sea Accessibility Index
0.803

Table 4: Sea Accessibility Index

The Sea Accessibility Index represents the level of ease with which individuals can access beaches in Sardinia via bus transportation. It is a measure that reflects the proximity of bus stops to the beaches. The index value ranges between 0 and 1: a higher value of the index implies better accessibility to the beaches from bus stops, while a lower value indicates poorer accessibility. A value of 1 signifies perfect accessibility, meaning

that all beaches are located very close to bus stops; conversely, a value of 0 suggests that beaches are located far away from bus stops, resulting in poor accessibility. The index could be inflated if multiple bus stops are clustered around certain beaches while many other beaches are not well-served by any stops. For this reason, we can calculate the coefficient of variation: *0.232*. The CV considers the standard deviation of the accessibility scores relative to their mean, higher values indicate greater variability in accessibility scores. Next, the Weighted Index: it takes into account both the average accessibility score and the coefficient of variation. We can use a weighted sum where the CV has a higher weight for lower values, indicating that it prioritize beaches with more consistent accessibility scores.

Sea Accessibility Index (Weighted)
0.617

Table 5: Weighted Sea Accessibility Index

A higher weighted index indicates that the beaches, on average, are well-served by bus stops and have consistent accessibility scores across different stops, while a lower weighted index suggests that the accessibility to the beaches is more variable or that there are beaches with low accessibility scores.

2.3 Analysis of the Results and Suggestions

After 'navigating' through this project, starting from the airport arrival and up to the current situation of public transportation in the province, it is now time to carry out a final analysis regarding the emerged gaps and the opportunities for growth and improvement to suggest to the relevant parties. The concluding idea is to display an image that encompasses various gaps, from municipalities without stops to beaches not accessible via public transportation. To achieve this, different dataframes have been constructed, each containing specific information, as visualized in the image below. The main dataset contains, for each row, the name of the municipality, geometric information, area, population, population density, kilometers to the nearest beach, and the number of stops available. The other datasets, filtered and/or constructed from information from various sources, provide the following information: (1) bus stops in Sassari, (2) beaches in Sassari, (3) municipalities with an insufficient number of stops compared to population density, (4) municipalities without stops, (5 and 6) beaches without stops within a radius of - respectively - 5 and 3 kilometers. Next, we can finally observe the complete visualization, containing all this information:

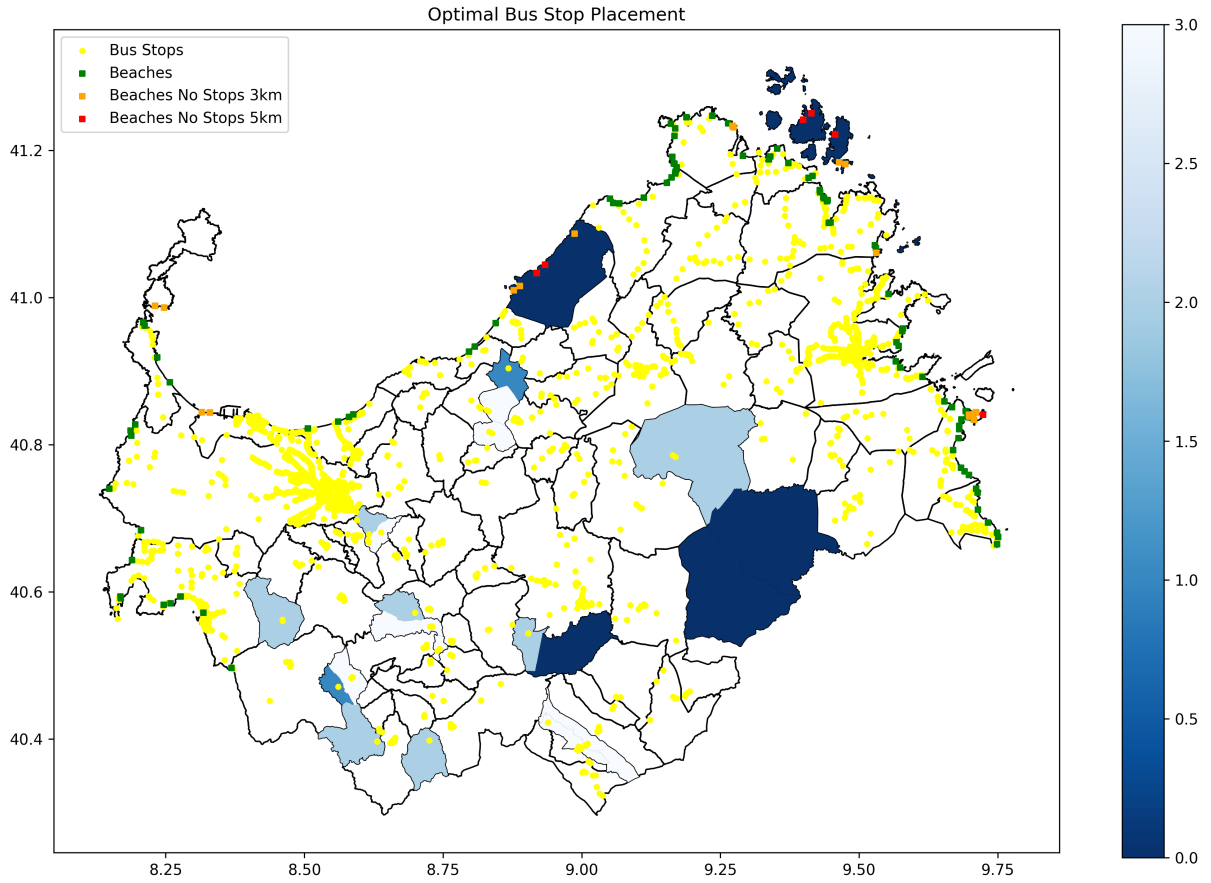

Figure 21: Optimal Bus Stop Placement

3 Conclusions and Future Developments

From parking lots to traffic, and more broadly, the quality of life for tourists and citizens. There are multiple factors at play, and the improvement of this issue involves economic, health, and more general aspects of the future for many. As we have observed from the analysis conducted, Olbia Airport is the one that receives the most traffic in terms of passenger flow in the area of interest. For both airports - Olbia and Alghero - the summer season is by far the busiest, and the province derives great strength and value from tourism, both from Italy and from foreign and international sources. We have also observed the general transportation situation, noting the obvious differences between inland regions and coastal ones. Public transportation stops are concentrated in some more developed and populated areas, while others are somewhat neglected. This represents a problem, which among many causes contributes to depopulation. Even in terms of tourism, however, some beaches are not served by public transportation. Therefore, the final visualization aimed to highlight the combination of these points to provide an idea of where and how to potentially intervene in the future to improve the situation. Fill gaps in public transports could be a solution, but, more broadly, other ideas need to be considered.

Apart from expanding coverage, future developments of this study can comprehend the analysis of frequency of the public transports, and the use of services like car sharing. In addition, considering pricing and accessibility of public transports is a relevant factor, the government can motivate citizens to take public transports by proposing more affordable

tickets, and multi-modal ticketing when available. Another point to consider in further analysis could be to study the accessibility for people with disabilities. As the city of Olbia recently did [6], promoting and investing in different infrastructures is a solution: from bike and pedestrian integration with public transportation stops, to new cycling paths. To conclude, studying the presence and possible developments of alternative mobility patterns, like cycling paths, is another point that would improve the overall analysis.

References

[1] Laura Alessandretti and Michael Szell. *Urban Mobility*. 2022. arXiv: 2211.00355 [physics.soc-ph].

[2] Redazione Ansa. *Caro noleggio auto Sardegna, "fino a 3000 euro per 7 giorni"*. URL: https://www.ansa.it/canale_motori/notizie/attualita/2022/05/14/caro-noleggio-auto-sardegna-fino-a-3000-euro-per-7-giorni_dae5f86d-abc2-4379-8a13-3df6cd06523e.html.

[3] Alessia Conzonato. *In Sardegna un bonus contro lo spopolamento: 15 mila euro a nuovi residenti (e attività)*. URL: https://www.corriere.it/economia/casa/22_novembre_12/sardegna-bonus-contro-spopolamento-15-mila-euro-nuovi-residenti-attivita-0929b2b8-3a61-11ed-b03d-1f9e636121b9.shtml (visited on 11/12/2022).

[4] Costantino Cossu. *La desertificazione antropica lascia vastissime aree della Sardegna nell'abbandono*. URL: https://ilmanifesto.it/la-desertificazione-antropica-lascia-vastissime-aree-della-sardegna-nellabbandono (visited on 08/12/2021).

[5] World Economic Forum. *Shaping the Future of Urban Development and Services Initiative*. 2021.

[6] Angela Galiberti. *Olbia: aggiudicati i lavori per la pista ciclabile sul mare*. URL: https://www.olbia.it/olbia-aggiudicati-i-lavori-per-la-pista-ciclabile-sul-mare.

[7] Sardegna Geoportale. *PPR06 - Campi dunari e sistemi di spiaggia*. URL: https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:UYYEX.

[8] UN-Habitat. *World Cities Report 2020: The Value of Sustainable Urbanization*. 2020. URL: https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization.

[9] IEA. *Global EV Outlook 2021*. 2021. URL: https://www.iea.org/reports/global-ev-outlook-2021.

[10] ISTAT. *Confini delle unità amministrative a fini statistici al 1° gennaio 2023*. URL: https://www.istat.it/it/archivio/222527.

[11] Paulo Antonio Maldonado Silveira Alonso Munhoz et al. "Smart Mobility: The Main Drivers for Increasing the Intelligence of Urban Mobility". In: *Sustainability* 12.24 (2020). ISSN: 2071-1050. DOI: 10.3390/su122410675. URL: https://www.mdpi.com/2071-1050/12/24/10675.

[12] Sardegna Mobilità. *Dati fermate trasporti Sardegna*. URL: https://www.sardegnamobilita.it/open-data/dati-fermate-trasporti-sardegna.

[13] Sardegna Mobilità. *Passeggeri giornalieri da porti e aeroporti*. URL: https://www.sardegnamobilita.it/open-data/passeggeri-giornalieri-da-porti-e-aeroporti.

[14] Sardegna Mobilità. *Statistiche flussi passeggeri degli aeroporti sardi*. URL: https://www.sardegnamobilita.it/open-data/statistiche-flussi-passeggeri-degli-aeroporti-sardi.

[15] Regione Autonoma della Sardegna. *Open data*. URL: https://www.sardegnamobilita.it/open-data.

[16] Regione Autonoma della Sardegna. *Province*. URL: https://www.sardegnaautonomie.it/province.

[17] Chiara Vitrano and Matteo Colleoni. "Mobility as a Service: Moving in the Desynchronized City". In: June 2020. ISBN: 9781138482197.

[18] Claudio Zoccheddu. *L'auto a noleggio nell'isola è una scelta obbligata, ma anche un salasso*. URL: https://www.lanuovasardegna.it/regione/2022/07/05/news/l-auto-a-noleggio-nell-isola-e-una-scelta-obbligata-ma-anche-un-salasso-1.100044374.