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Cycling Uptake and User Experience in Sustainable Employee Commuting: GreenPATH Monza

TESI DI LAUREA MAGISTRALE IN
MOBILITY ENGINEERING

Author: **Rama Surya Sai Palivela**

Student ID: 245567

Advisor: Prof. Pierluigi Coppola

Co-advisors: Arch. Andrea Piantoni

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Abstract

A medium-sized city with narrow streets, residential buildings, bus depots, and a multi-modal hub located in the city center faces a wide range of challenges in urban sustainability. Public spaces must accommodate many competing functions, including bus stops, bike lanes, sidewalks, and parking for both private and public vehicles. In particular, commuting during the rush hours is more challenging due to high dependence on private vehicles, which contributes to poor air quality, longer travel times, congestion, and increased commuter stress. The GreenPATH Monza pilot, developed within the Interreg Central Europe GreenPATH project, was designed to encourage sustainable employee commuting through a combination of digital tools, incentives, and gamified engagements. The thesis is based on data collected during the pilot through GPS-supported bicycle tracking and app-based surveys. A descriptive analysis was carried out to identify main patterns using Python, and the rush-hour movements, most frequently used routes, fast and slow corridors based on velocity attributes, origin-destination patterns during rush-hours were explored in ArcGIS Pro. The study contributes to how gamified bicycle commute initiatives can support sustainable employee mobility and highlights the importance of protected infrastructure and route quality to maintain cycling for long-term.

Keywords: Sustainable commuting, Gamification, GPS tracking, Bicycle infrastructure

Abstract in italiano

Una città di medie dimensioni con strade strette, edifici residenziali, depositi di autobus e un hub multimodale situato nel centro della città si trova ad affrontare un'ampia gamma di sfide in termini di sostenibilità urbana. Lo spazio pubblico deve ospitare molte funzioni concorrenti, tra cui fermate degli autobus, piste ciclabili, marciapiedi e parcheggi sia per veicoli privati che pubblici. In particolare, spostarsi nelle ore di punta è più impegnativo a causa dell'elevata dipendenza dai veicoli privati, che contribuisce alla scarsa qualità dell'aria, ai tempi di percorrenza più lunghi, alla congestione e all'aumento dello stress dei pendolari. Il progetto pilota GreenPATH Monza, sviluppato nell'ambito del progetto europeo Interreg Central Europe "GreenPATH", è stato ideato dal Comune di Monza per incoraggiare il pendolarismo sostenibile dei dipendenti attraverso una combinazione di strumenti digitali, incentivi e processi di gamification (l'utilizzo di elementi e meccaniche di gioco come punteggi, badge, classifiche e sfide). La tesi si basa sui dati raccolti durante il progetto pilota attraverso il tracciamento GPS degli spostamenti in bicicletta dei dipendenti delle grandi aziende del territorio tramite appositi dispositivi agganciati alle biciclette e collegati ad un'app per smartphone e tramite sondaggi in-app. È stata condotta un'analisi descrittiva per identificare i modelli principali utilizzando Python e in ArcGIS Pro si sono esplorati i percorsi più frequentemente utilizzati, i corridoi veloci e lenti basati sugli attributi di velocità, i modelli origine-destinazione e i movimenti nelle ore di punta. Lo studio contribuisce a spiegare come le iniziative volte ad incentivare gli spostamenti in bicicletta, in particolare tramite gamification, possano supportare una mobilità sostenibile dei dipendenti e sottolinea l'importanza di infrastrutture protette e della qualità dei percorsi per mantenere l'uso della bicicletta a lungo termine.

Parole chiave: Pendolarismo sostenibile, Gamification, Localizzazione GPS, Infrastrutture ciclabili

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1 | Introduction

Urban mobility is one of the main challenges in many cities today. Every day, large numbers of people travel to work, school, and other daily activities. When most of these trips are made by private cars or motorbikes, cities face many problems, such as traffic congestion, air pollution, lack of public space, and stress during commuting hours. These problems become stronger in medium-sized cities where daily movements are concentrated during the morning and evening rush hours. In this context, sustainable commuting has become an important topic in urban mobility planning. Sustainable commuting means using transport modes that reduce environmental impact. The bicycle is one of the most promising options, especially for short and medium urban trips. Cycling can help reduce traffic, improve air quality, lower commuting costs, and support a healthier lifestyle. At the same time, many people still do not use bicycles regularly for commuting due to several practical problems, such as unsafe routes, missing cycling lanes, a lack of supporting facilities, and poor comfort during trips. In response to these challenges, many cities and institutions are exploring new ways to encourage more sustainable travel behaviour in daily commuting and to study how people respond to alternative mobility options in real-life conditions.

GREENPATH is an **INTER-REGIONAL CENTRAL EUROPEAN PROJECT** aimed at providing sustainable commuting solutions to students and employees together with mobility managers in Functional Urban Areas (FUAs). The GreenPATH project, led by the Institute for Transport and Logistics (ITL, Italy), was officially launched in Bologna in May 2024 and is scheduled for completion in October 2026. The project promotes modal shift towards more sustainable transport modes and active mobility by engaging stakeholders, companies, universities, public authorities, and citizens to drive positive changes in commuting habits. The goal is to reduce greenhouse gas emissions, improve transport efficiency, and enhance the commuting experience for workers and students. The Pilots focusing on student commuting are BOKU University (Vienna), University of Maribor (UM), and Technische Universität Berlin (TUB). The Comune di Monza (Monza, Italy), Dyvolve (Osijek), KeKo (Kecskemet), and Ravenna (Italy) are the pilots targeting employee commuting.



Figure 1.1: GreenPATH Partners & Pilots

As the **COMUNE DI MONZA** (Municipality of Monza) represents one of the employee commuting pilot cities, understanding the city's transport conditions, in relation to its demographic, spatial, and mobility characteristics, is important.

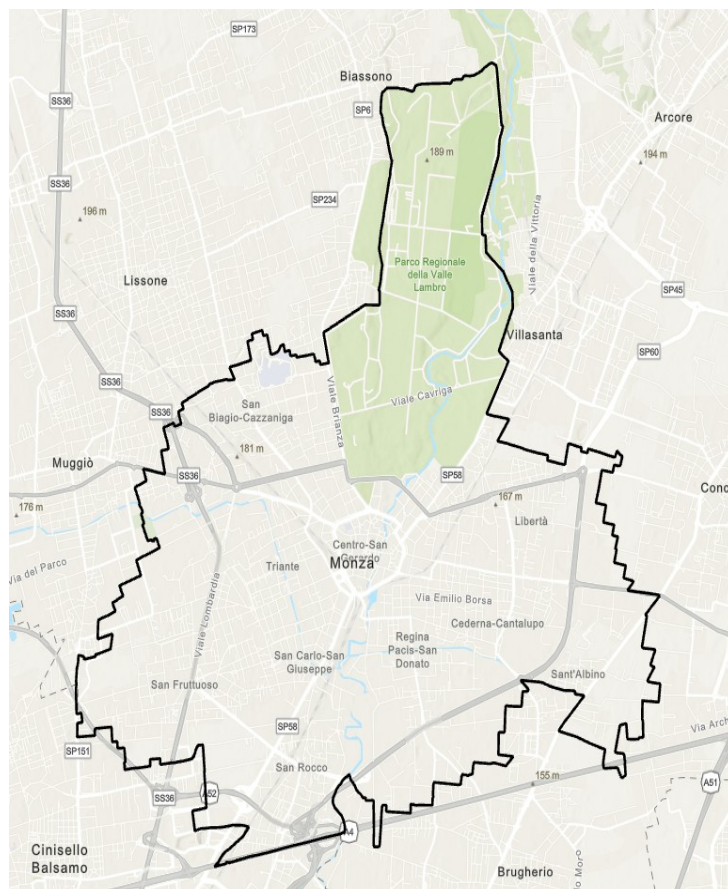


Figure 1.2: Map of Municipality of Monza

The city of Monza is located in the north of Italy, 15 kms north of Milan. It is the main city of its province, which borders the province of Milano. The Municipality of Monza has around 125.000 inhabitants with an area of 33 sq.km, it's the 3rd most populous city in Lombardy region and the 5th most populous capital city in Italy in population density. The city also has a mobility system that includes transport services and facilities. Monza has 410 bus stops, 15 bus lines, and 2 train stations. In relation to cycling, the city has 3 bicycle parking areas with space for 300 bicycles, many bicycle racks, 58.8 km of cycling paths, and a bike-sharing system with 22 stations, 100 station bikes, and 200 free-floating bikes. The city has infrastructure and services to support sustainable mobility, including cycling.

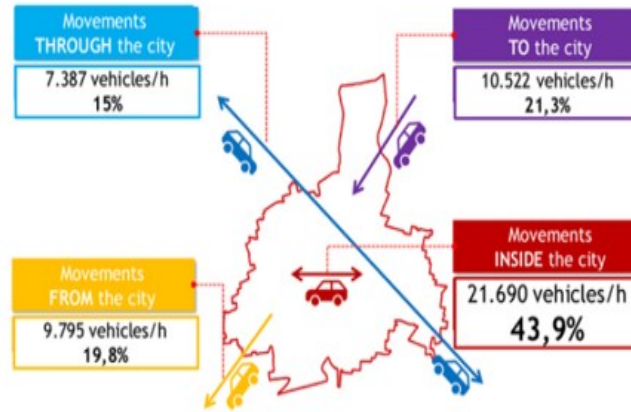


Figure 1.3: Rush hour Vehicle Movements

Monza has a strong daily mobility demand. From the SUMP (sustainable urban mobility plan) during rush hours, the study area records 7,387 vehicles per hour (15%) moving through the area, 10,522 vehicles per hour (21.3%) moving into the area, 9,795 vehicles per hour (19.8%) moving out of the area, and 21,690 vehicles per hour (43.9%) moving inside the area [5]. This shows that Monza has a high concentration of everyday commuting movements. The high vehicular density during rush hours contributes to traffic congestion and road safety, as well as poor air quality in relation to PM2.5 concentrations. These conditions make Monza a relevant case for studying how bicycle commuting can be encouraged and what kind of support is still needed to make it more attractive and safer for everyday use.

The GreenPATH project in Monza is presented by the municipality as "**GreenPATH Monza**" and started in May 2024. The Key Objectives of the project are:

- To reduce congestion and accidents, resulting in safer and more secure streets
- To improve urban air quality and to make cars occupy fewer public spaces by dedicating more significant public spaces
- To understand the cyclists' needs and the preferred paths, and to implement the new bicycle paths



Figure 1.4: GreenPATH Monza Pilot Logo

It promotes cycling as a daily commuting option through a combination of Gamification, Incentives, digital tools and awareness activities. The employees of the Municipality of Monza and 12 participating companies, a total of 265 employees, are registered and are encouraged to use bicycles to commute to work, as well as during their free time, as an alternative to environmentally unsustainable travel. The Bike kit distributed to the participants consists of a GPS device that certifies the travelled distance by bike (the additional items in the kit are an LED signal light, a reflective plate, and an adaptor valve to allow tyre inflation). The project requires the installation of a GPS device on the bicycles of the employees involved. The GPS device allows for monitoring the bike traffic and preferred routes easily and precisely. An external service provider's **Private Dashboard** acts as the operational interface of the GreenPATH Monza project. It includes different sections that support both monitoring and management of the pilot.

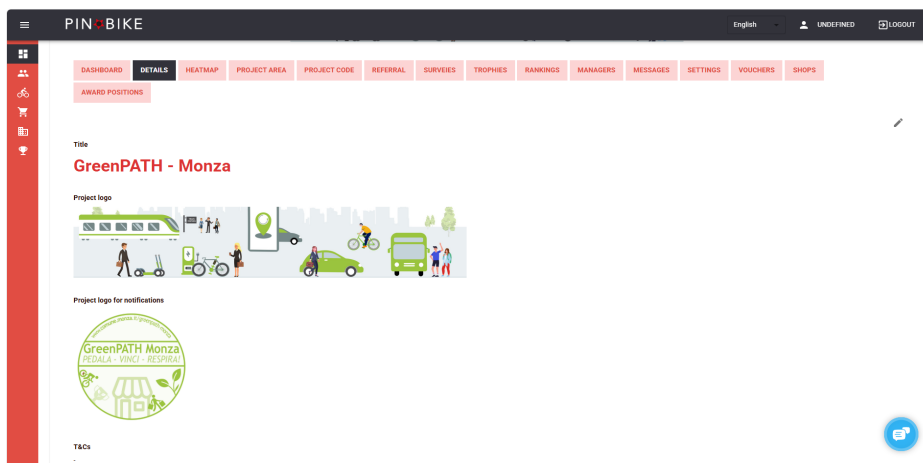


Figure 1.5: Dashboard of External Provider

The private dashboard also includes Surveys, Trophies, Rankings, Award Positions, and Vouchers, which are directly linked to the gamification system of the pilot. It tracks kilometers cycled by the commuters and rewards sustainable mobility behaviour. These sections help manage questionnaires, participation rewards, rankings, and the incentive mechanism. Additional sections, such as communication with users and the management of local shops connected to the voucher system.

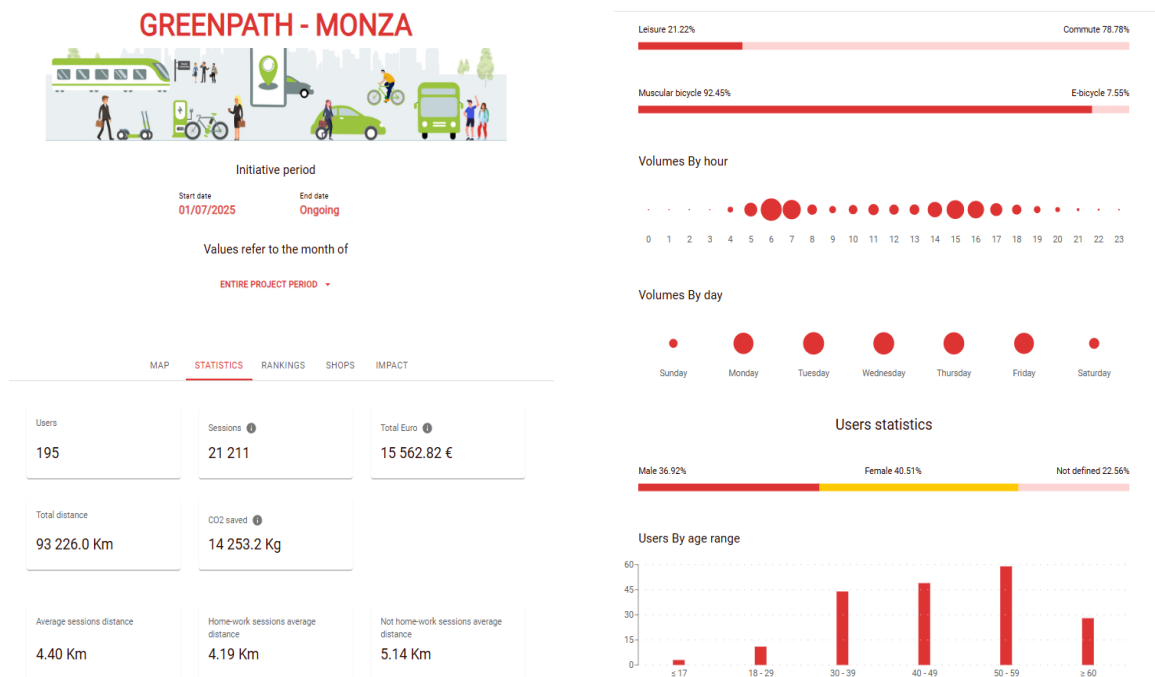


Figure 1.6: GreenPATH Monza Public Dashboard

The Pilot also provides real-time monitoring through a **Public Dashboard**, providing a general overview of the GreenPATH Monza initiative through aggregated project indicators and helping the municipality and users better understand cycling flows and mobility patterns. It reports the number of active users, total sessions, total distance travelled, total vouchers generated in euros, and estimated CO2 saved, which helps summarise the overall scale of the cycling activity recorded during the project.

The dashboard also distinguishes between home-to-work and non-home-to-work trips, showing average session distances and the share of trips for commuting and leisure. This is useful for understanding whether the recorded bicycle activity is mainly linked to daily commuting or to other purposes. Another important section of the dashboard shows the temporal distribution of trips by hour and by day. This makes it possible to identify the main activity peaks and to observe how cycling behaviour changes across the week. The dashboard further includes basic user statistics, such as gender distribution and age range,

which help describe the profile of the participants involved in the initiative. The public dashboard combines mobility indicators, behavioural patterns, and participant characteristics into a single interface, providing a quick summary of the project's performance.

The Pin Bike **Mobile Application** is used by participants as the main interface for monitoring their activity and interacting with the project. To record a trip, users have to start and stop the session in the mobile application before beginning and after the end of their journey. It allows users to view project information, vouchers, travelled distance, and CO₂ savings, while also recording trip details such as time, distance, and speed during an ongoing cycling session. Survey notifications were sent to users through the mobile application and email for questionnaire completion.

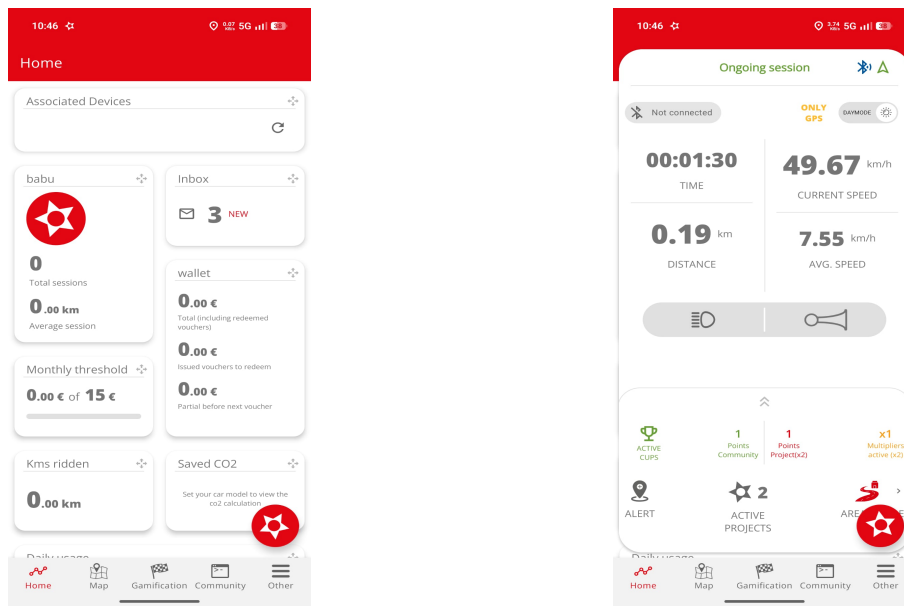


Figure 1.7: Interface of the Pin Bike mobile application

The thesis focuses on the GPS-based cycling data and app-based survey data to analyse the practical and spatial dimensions and to evaluate actions to improve cycling in the city of Monza.

2 | State of Art

Cycling is an important part of sustainable urban mobility. In cities, many daily trips are short or medium in distance, which makes the bicycle a practical option for commuting. Compared to private motorized transport, cycling can help reduce greenhouse gas emissions, traffic congestion, air pollution, and noise, while also bringing health benefits for users [3]. Many cities have started investing more in cycling infrastructure and cycling-related policies [3]. These include the implementation of new bicycle lanes, bicycle parking, bike-sharing systems, and promotion of e-bikes.

Cycling is not only an environmental solution, but it is also a daily travel choice. People are more likely to bike when the travel efficiency and level of comfort are acceptable. The other factors like route quality, directness, and continuity all influences to see cycling as an alternative to the private car or other travel modes. The cycling is not experienced in the same way across all the routes. The literature shows that cycling is strongly influenced by infrastructure quality, safety conditions, and the way users perceive their travel environment. For this reason, the study of cycling should not rely only on objective measures such as kilometers of bicycle lanes or network length. The speed and effort change according to the slopes, curves, intersections, and weather conditions [2]. The studies also show that bicycle use may increase when cities introduce restrictions on motorized traffic or improve the attractiveness of alternative modes [3]. It should be seen as both a sustainable transport mode and a practical commuting option. The GreenPATH Monza pilot is not only about encouraging cycling, but also about understanding whether bicycle commuting can work as a realistic and attractive option for employees.

The studies show that GPS-based cycling data provides a more detailed understanding of bicycle movement in urban areas. Unlike manual counts or fixed counters, GPS data can capture the full route of a trip and support the analysis of bicycle volume, route choice, traffic patterns, and cycling behavior across the network [7]. Also, GPS traces to study heat maps, safety conditions, and traffic parameters such as speed and delays [10]. The GreenPATH Monza pilot also included GPS-based bicycle trajectories to support spatial analysis of cycling flows and route use in the city.

Alongside GPS-based route data, app-based participation can also support the collection of user-reported information during cycling projects. Smartphone applications are useful in behavioral interventions because they make data sharing easier and allow users to interact directly with the program. In cycling encouragement campaigns, app use has been shown to increase participation and trip entry, especially when combined with Gamification elements [10], and also can generate useful information on cycling activity, rider characteristics, motivations, and perceived barriers to riding. This makes app-based tools valuable not only for encouraging cycling but also for collecting user-oriented data during the project.

2.1. Nudging

Nudging refers to a specific element within the choice architecture that influences people's behavior without prohibiting choices or altering their economic incentives [8]. Nudges are small, gentle adjustments to the environment that make it easier for people to choose sustainable options without forcing them. In the transport sector, behavioral change is important because technological improvements like cleaner or alternative fuels, electric vehicles, vehicle design, & digital infrastructures alone are not enough to reduce emissions, to decongest cities, and to improve the urban air quality. For this reason, soft behavioral measures such as nudges are increasingly discussed as complementary tools for sustainable transport policies [4]. When attempting to change behavior or gain acceptance of policies, it is crucial to take into account the various factors surrounding these choices and acceptance. One way to approach this is to consider the motivating factors behind a particular behavior [1].

The mobility behavior of most of the people follows the same travel routines every day, with particular focus on employee commuting. It makes their travel choices stable over time. Even when more sustainable choices are available, it is not always easy to change mobility behavior. Here, nudging offers a gentle way to encourage people to rethink their habits without forcing them to change. The travel decisions are also influenced by the perceived convenience, habits, efforts, and personal motivation, not only by travel time and cost. For many, driving a private car feels the safest, most convenient choice. In such cases, nudging helps to reduce the mental and practical barriers that prevent people from trying alternatives like cycling, walking, or public transportation by making these sustainable choices feel easier and more accessible.

Nudging can be applied in many ways: information-based nudges, social norm nudges, changes to the physical or digital choice environment, and messages that highlight personal benefits, such as health or cost savings [1]. They work best when they fit the specific situation and when they are supported by good public transportation, accessibility, and safe infrastructure. This thesis looks at the GreenPATH Monza project as a real-world example of these ideas in action. The project didn't force employees to stop using private cars. In the case of GreenPATH Monza, cycling is encouraged through gamification, incentives, app-based interaction, and participation activities rather than through compulsory restrictions. By focusing on these kinds of activities, the project shows how behavioral strategies can help to support people in making more sustainable choices during their daily commute.

3 | Gamification in the GreenPATH Monza

In the mobility context, Gamification can be understood as the use of game-like elements such as leader boards, badges, points, challenges, prizes, and personalized notifications to encourage user participation and influence travel behavior. The studies say that Gamification is more effective when it is combined with other measures, such as financial incentives, information, and personalized feedback [4]. The participants involved in the pilot were the employees of the Municipality of Monza and the employees of the other 11 companies located in Monza. With the involvement of Mobility Managers, about 200 employees were registered in the pilot to commute by bike. In particular, 265 requests were received, 38 were denied, 18 registered participants did not collect the kit, 209 collected the kit, and 195 became active users. Gamification makes the commuting experience more active for participants because their behavior is linked to visible outcomes such as vouchers, rankings, and participation rewards.

3.1. Registration and Distribution of Bike Kits

As a first step of the pilot, a total of 209 kits were distributed to the participants. The bike kit includes a GPS device, an LED signal light, a reflective plate, and access to the Pin Bike mobile application with an user manual. The participants were required to mount a GPS device on their bicycles, which identifies the routes perceived and certifies the traveled distance. Once the device is installed and the bicycle is connected to the initiative, the participant becomes an active part of the Pilot. The GPS device on the bicycle works together with the Pin Bike mobile application. Through the application, the participant is linked to the initiative to receive information and take part in the reward system. The participants must record the start and the end of their trips in the mobile application. It is the main interface between the users and the pilot. The administration part of the platform allows the pilot managers to monitor the project, check budget spending, create initiatives, and communicate with the users.

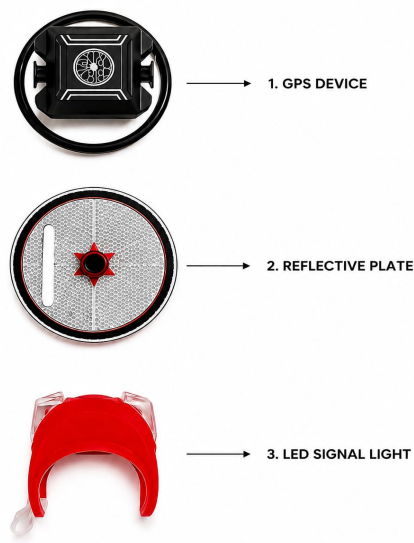


Figure 3.1: Main Components of the Bike kit distributed

3.2. Mileage reimbursement and Monthly Rankings

The cycling was not only monitored but also rewarded. The mileage reimbursement rewarded bicycle use based on kilometers traveled. The total mileage covered applies to the home-to-work trips counted, regardless of the study area, and generic trips (non-home-to-work trips) counted only inside the study area.

- Participants receive EUR 0.30 per kilometer
- Maximum of EUR 2.00 per day
- Maximum of EUR 15.00 per month through vouchers

The sums relating to the mileage reimbursement, upon reaching the threshold of EUR 10.00, will be available in the form of electronic vouchers, which can be spent, individually or cumulatively, at any of the 6 local shops that are registered in Pilot. Also, based on the number of home-to-work sessions completed during the month, given monthly rankings for top five participants receive extra vouchers. The monthly ranking was based on sessions, not kilometers.

- EUR 50 for first place
- EUR 40 for the second and EUR 30 for the third place

- EUR 20 for the fourth and EUR 10 for the fifth

At the end of the Pilot, participants returning the GPS device receive a EUR 10 voucher. This Gamification tool encourages employees to choose the bicycle more often for their trips to work. The reimbursement gives a regular and measurable reward linked to effort, while the ranking introduces a competitive element. Some users are motivated by direct rewards, while others may respond more to competition, progress, or recognition. It creates a mixed system of economic benefit and competitive motivation.

3.3. Participation-based rewards and engagement

The pilot also included a Participation ranking to reward beyond the cycling distance and commuting sessions. This ranking considered participation in surveys and initiatives through the app, as well as attending project events, over the period of the pilot. Participants who attended the events by bike received 100 points.

The awareness and engagement activities, such as workshops, campaigns, and local events, were held by **FIAB (Federazione Italiana Ambiente e Bicicletta)**. On 15th November 2025, Monza hosted a series of hands-on cycling workshops at the historic Mulini Asciutti, Monza, to discover how cycling can become a reliable and comfortable part of daily life. The workshops were designed to address issues such as bike theft, weather conditions, or carrying everyday items, cycling in the rain, and shopping by bike, providing practical tips and expert advice. The participants learned the importance of choosing a reliable lock, securing the bike frame rather than only the wheel, and selecting visible and safe parking locations. In session focused on cycling in the rain, presented simple solutions such as waterproofing clothing, breathable layers to avoid overheating, and reflective elements to improve visibility in low-light conditions.

Beyond the cycling skills, the workshops also highlighted how bicycles can integrate into broader mobility systems. Participants learned how to combine cycling with public transport, discovering access rules for bikes on metro systems and regional trains, and discussing how bicycle parking at stations can support multimodal commuting. Another engaging session explored shopping by bike, presented practical solutions such as baskets, panniers, and cargo options that make every day both feasible and sustainable. Finally, the participant discovered how digital tools and cycling apps can support safer route planning and track commuting behaviour, contributing to the monitoring activities of the GreenPATH pilot. The Hands-on workshops organized by the Municipality of Monza helped citizens and workers gain practical skills to integrate cycling into their everyday mobility choices.

4 | Data and Methods

4.1. Data sources

The analysis developed in this thesis is based on two sources of data collected during the GreenPATH Monza pilot: **GPS trajectory data and App-based survey data**. The GPS trajectory data was generated during the pilot and provided by an external service provider. These data record the actual bicycle movements of users and make it possible to observe route concentration, speed-related patterns, and the spatial distribution of cycling trips in Monza.

The app-based survey data were collected during the GreenPATH Monza pilot. These survey data represent the main basis of the descriptive analysis developed in the thesis. The questionnaires were designed to gather information directly from the participants about their commuting conditions, their experience with cycling, and their view of the local cycling network. The combination of these two data sources is important for the pilot and the thesis. The survey data provide information on how users describe and evaluate their commuting experience, while the GPS data provide an observed view of how cycling movements are distributed in space and time.

4.2. GPS-based route analysis in ArcGIS Pro

As the participants joined in the pilot, they received a bike kit and installed a GPS device on their bicycle, which worked together with the Pin Bike application and platform. Through this system, bicycle trips could be tracked and monitored in real time, making it possible to record the spatial and temporal structure of cycling activity during the project. The available GPS-based information is useful as it goes beyond the reported behavior and provides direct evidence of where and when cycling actually took place. In the Monza pilot, the system was used not only to certify kilometers traveled for the incentive mechanism, but also to support a public dashboard for monitoring cycling flows and mobility patterns. Publicly visible indicators from the dashboard include measures such as average distance of home-to-work sessions, average distance of non-home-to-work

sessions, average trip distance, cycle path travel percentage, and volumes by day and hour, as well as CO₂ saved [6], showing that the dataset can support both trip measurement and broader mobility interpretation. The public dashboard also allows the visualization of monthly heat maps, participant rankings, and the shops enrolled in the Gamification.

Here, the GPS data are used to study the observed spatial behavior of cyclists during the pilot. Unlike survey responses, which describe perceptions and self-reported experience, GPS trajectories provide route-based information that can be used to identify the most used corridors, compare faster and slower route segments, examine trip origins and destinations, and distinguish patterns by time of day or day type. For this reason, the GPS dataset is an important part of the thesis, as it supports the spatial interpretation of bicycle commuting in Monza.

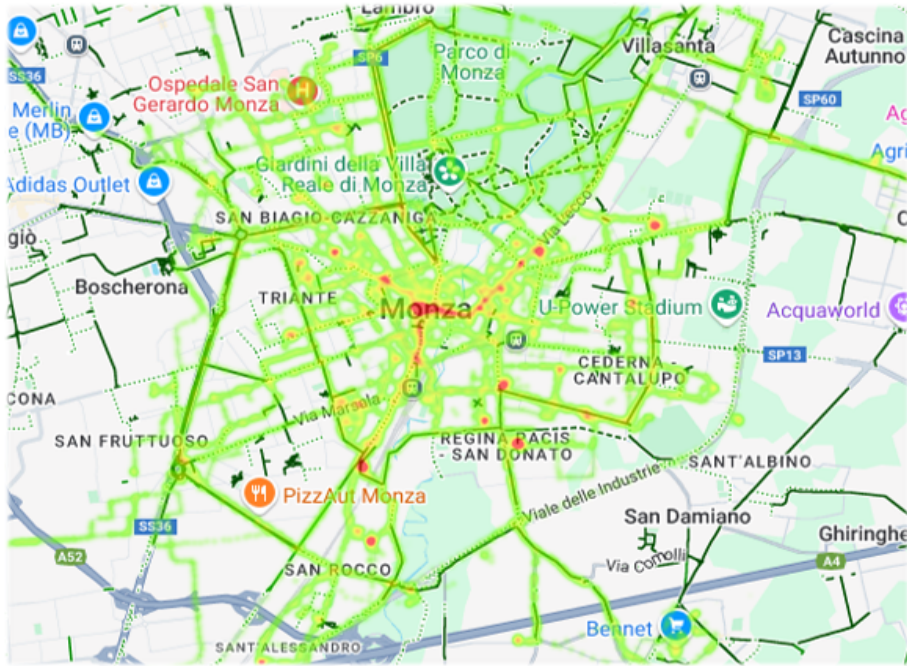


Figure 4.1: HeatMap of Bicycle Movements [6]

The GPS-based trajectory dataset for a period from July 2025 to March 2026 is provided in point format, representing individual cycling movements. Each record corresponds to a geographic point collected along a cyclist's route and contains spatial coordinates. The key attributes include a unique session identifier (ID_Session), which represents an individual trip, and a timestamp field (Timestamp_DT), which records the exact date and time of each observation. Additional variables, such as Time_Hour, were derived to support temporal analysis of cycling activity. The dataset also includes movement-

related attributes such as `velocity_k` (cycling speed), which allows for the analysis of travel behavior and identification of fast and slow corridors. Spatial attributes (geometry) store the geographic location of each point, enabling mapping and spatial analysis.

Unlike survey responses, which described perceptions and self-reported experience, GPS trajectories provide route-based information that can be used to identify the morning and evening rush hours, most used corridors, compare faster and slower route segments, examine trip origins and destinations, and distinguish patterns by time of day or day type.

- Rush-hours during morning and evening are identified using the timestamp field, which makes it possible to filter trips by time of day and isolate the periods that are most relevant for commuting activity.
- The most used routes can be identified by mapping and aggregating repeated GPS trajectories. A kernel density-based method is used to highlight the corridors with the highest concentration of bicycle movements during rush hours and non-rush hours.
- The analysis of fast and slow corridors is based on the velocity attribute available in the GPS table. This makes it possible to compare route segments according to relative speed and to identify corridors that appear efficient from a travel-time point of view.
- Origin–destination patterns are studied by extracting the start points and end points of the recorded trips. This allows a first reading of where bicycle trips begin and end.

These approaches in Arc GIS Pro make it possible to understand bicycle commuting as a mobility pattern in the spatial structure of the city.

4.3. Survey structure and modules

The survey data were organized into five modules, each covering a different aspect of the commuting experience. Each module was analyzed to maintain its specific focus.

- Module 1 focused on **the company headquarters infrastructure and facilities**. It included questions related to bicycle parking, cycling-related services such as showers or lockers, and the presence of protected path access to the workplace.

- Module 2 about **the route preferences in Monza**. It explored which routes users considered most important for new cycling infrastructure, which existing routes should be redeveloped, and which cycling paths were most preferred.
- Module 3 focused on **obstacles to cycling and travel-time comparison**. It investigated the main barriers discouraging bicycle use, the transport modes used when cycling was not chosen, and the comparison between bicycle travel time and usual transport.
- Module 4 focused on **travel habits before and during the pilot**. It included information on the transport mode used before the pilot, commute time, daily cost, and daily travelled distance.
- Module 5 focused on **satisfaction and feedback before and during the pilot**. It examined changes in satisfaction, perceived speed and convenience, stress, and safety.

4.4. Descriptive analysis approach

Descriptive analysis is a basic statistical approach used to summarize, organize, and present the main features of a dataset. Since the number of observations was limited, descriptive analysis was considered the most suitable approach for presenting and interpreting the survey results. This approach was chosen to show how respondents described their commuting experience during the pilot and to identify the most relevant trends in the participants' responses. Descriptive analysis was used to understand:

- How many respondents had bicycle parking at the workplace?
- Which barriers were mentioned most often?
- Which routes were preferred or considered in need of improvement?
- How did commute time and daily cost change during the pilot?
- How did satisfaction, convenience, stress, and safety change before and during the pilot?

The data was examined through frequencies, Percentages, Averages, Before vs During comparisons, Graphical representations such as bar charts, donut charts, and distribution charts.

5 | Results from the Application

This chapter presents the results obtained from the GreenPATH Monza pilot. The results are organised into two main parts: first, the GIS-based analysis of GPS trajectory data, and second, the descriptive analysis of the app-based survey. In this way, the chapter combines the spatial observation of bicycle movements with the user-reported experience of commuting in Monza.

5.1. Analysis of GPS-based data in ArcGIS Pro

The GPS trajectory dataset available from July 2025 to March 2026 was analyzed in ArcGIS Pro for spatial and temporal patterns of cycling activities. The point-based data structure allowed for the application of geospatial analysis techniques to derive key indicators of urban mobility. The analysis involved several sequential steps, including temporal aggregation, spatial transformation, and density-based modeling. Temporal attributes were used to identify peak activity periods, while the spatial analysis tool, kernel density estimation, was applied to identify patterns of route usage and activity concentration. The movement characteristics derived from velocity data were used to assess network performance by identifying fast and slow cycling corridors.

The integration of spatial and temporal analytical methods allowed for understanding the cycling behavior, linking when trips occur, where they take place, and how movement is performed across the network. This framework forms the basis for the results presented in the following sections, including the identification of rush hours, most frequently used routes, and origin–destination patterns.

5.1.1. Rush Hour Analysis

The temporal distribution of GPS bicycle movements shows that cycling activity was not evenly distributed throughout the day. The data show clear peak periods corresponding to the hours when the highest concentration of bicycle movements was recorded. This pattern makes it possible to identify the rush hours associated with the commuting behavior

of the participants. Based on the hourly frequency analysis, the highest concentration of bicycle movements, 68.227 trips, was observed during the morning period between 7:30-8:30 hours, while a second concentration of 56.060 trips was recorded during the evening period between 16:30-17:30 hours. These time intervals can therefore be considered the main rush hours of bicycle commuting in Monza within the dataset.

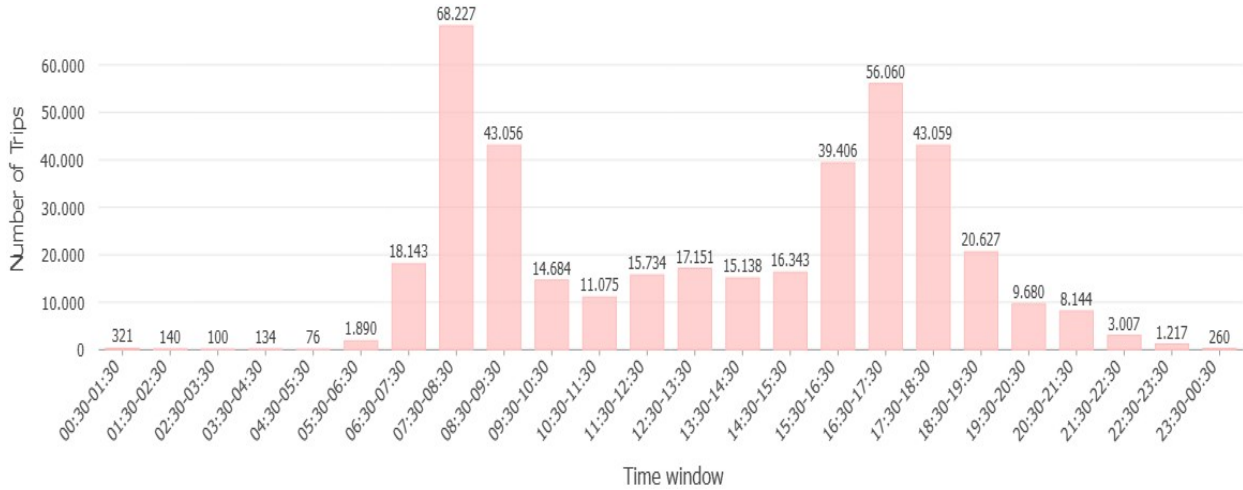


Figure 5.1: Distribution of Cycling Trips by Time Interval

The concentration of trips during the identified peak periods are commuting-related use, in the case of home-to-work. Outside these hours, cycling activity was lower and more dispersed, which may reflect more occasional trips, non-work-related movements, or leisure use. By identifying the rush hours, it is now possible to identify which routes and corridors that are most important to daily commuting.

5.1.2. Most used Routes

To identify the most frequently used cycling routes in morning and evening rush hours during the pilot phase, a kernel density estimation (KDE) analysis was applied to the GPS trajectory point dataset in ArcGIS Pro. The method converted discrete point observations into a continuous surface representing the spatial intensity of cycling activity. Each GPS point contributes to a density surface based on its spatial location, and the resulting raster highlights areas with high concentrations of cycling movements. The kernel density analysis was performed using a cell size of 20 meters and a search radius of 100 meters, allowing the identification of route-level patterns.

The resulting density surface was visualized using a graduated color scheme to highlight areas of varying intensity. High-density values indicate frequently used cycling routes, while low-density values represent less-utilized areas of the network. The identified corridors, such as "Via Lecco, Via Carlo Prina, Via Corso Milano, Via Borgazzi, Viale Brianza", as well as within the city center of Monza, can be interpreted as the foundation of the cycling network, serving as key pathways for movement across the city.

The figure 5.2 shows the most used cycling routes during rush hours. The central area of Monza highlights higher usage intensity, with radial corridors connecting peripheral areas to the city center. The values represented in the legend correspond to the output of the kernel density estimation and indicate the relative intensity of cycling activity. These values do not represent absolute counts of cyclists or trips, but rather a spatially smoothed measure of the concentration of GPS trajectory points. Lower values (approaching 0) indicate areas with less or no cycling activity, while higher values correspond to locations where cycling movements are highly concentrated. The maximum value observed (266,041) represents the highest intensity of route usage, primarily along the main corridors in the city center.

By comparing the rush-hour density map with the Module 2 results, "**Via Borgazzi, Via Lecco, and Corso Milano**" appeared both in the survey responses and in the GPS-based results. The "Viale Cesare Battisti is seen mentioned as a favourite route (Figure 5.19) and as a route needing redevelopment (Figure 5.18), where "Via Lecco" is mentioned as a corridor for the construction of a new bike path. These represent key mobility paths for daily commuting. These routes are important from a planning perspective, as they indicate where cycling demand is concentrated and where infrastructure improvements could have the greatest impact.

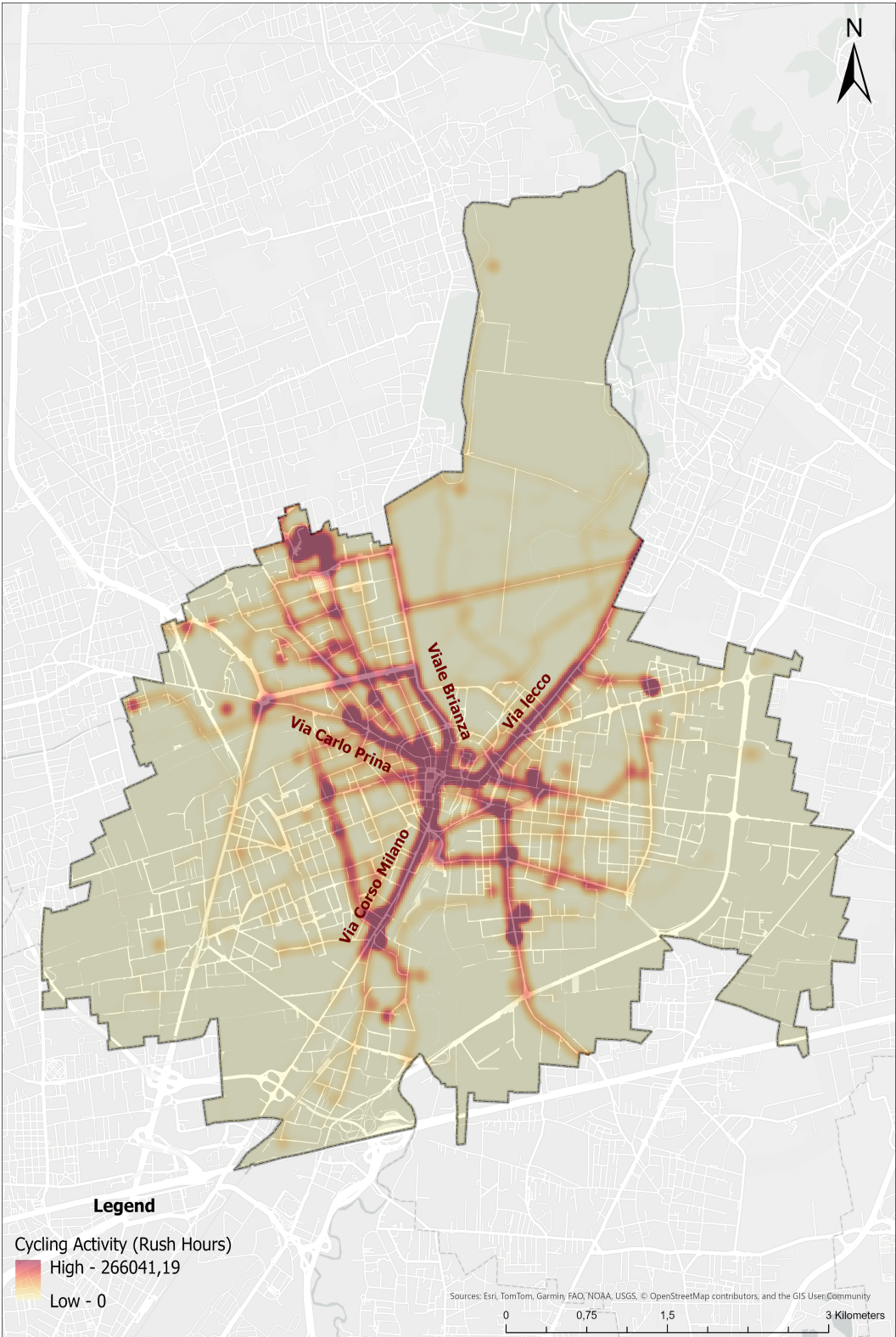


Figure 5.2: Most used Cycling routes

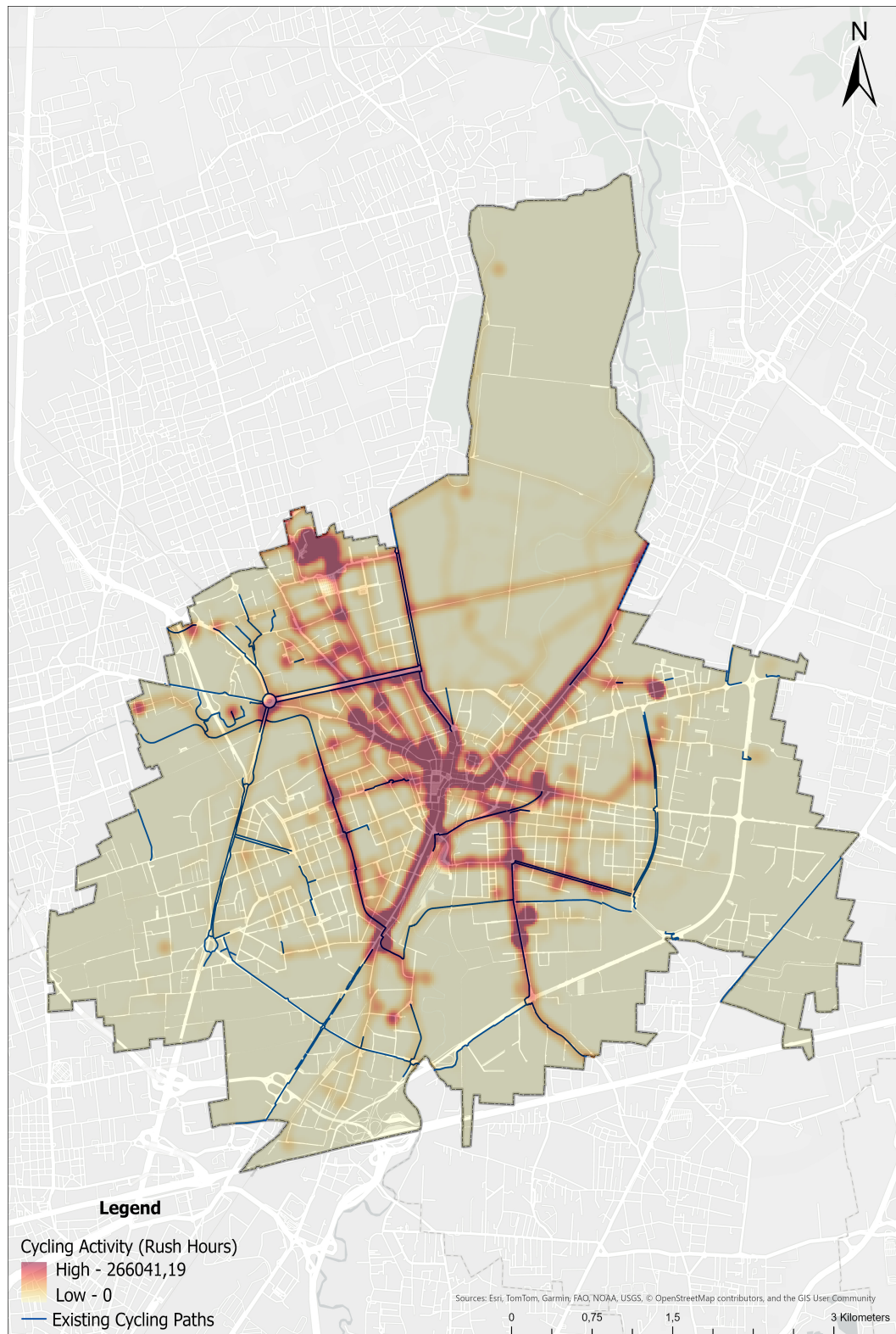


Figure 5.3: Overlay of Cycling activity routes with Existing Infrastructure

To further evaluate the relation between observed cycling demand in morning and evening rush hours and current infrastructure, the kernel density map was layered with the existing cycling-path network. This comparison shows that the present infrastructure only partly corresponds to the spatial concentration of bicycle movements. While some high-intensity corridors overlap with existing cycling paths, several of the strongest rush-hour routes appear only partially supported by dedicated infrastructure. This suggests that cycling demand in Monza is more concentrated than the current cycling-path network and that some corridors already function as important bicycle routes despite incomplete infrastructure coverage.

5.1.3. Fast vs Slow Corridors (Performance Analysis)

To evaluate the performance of the cycling network, a weighted kernel density analysis was conducted using cycling speed as an indicator of movement efficiency. Each GPS point was assigned a score based on velocity values, where higher speeds above 15 km/h were associated with positive values and lower speeds below 10 km/h with negative values. The analysis was performed using a cell size of 20 meters and a search radius of 100 meters, ensuring consistency with the route density analysis. Positive values indicate areas dominated by higher cycling speeds, reflecting efficient movement conditions, while negative values indicate areas where slower movement is more prevalent. Values near zero represent a balance between fast and slow movements. These values do not correspond to actual speeds, but rather to a relative performance index derived from spatial aggregation of speed-based weights.

The resulting map, layered with the existing cycling network, reveals a heterogeneous pattern of cycling performance across the study area. Linear features corresponding to fast corridors are observed along major routes, indicating areas where cyclists are able to maintain higher speeds and experience fewer interruptions. In contrast, clusters of low-performance areas are concentrated primarily within the central urban area of Monza and at key intersections. These locations are characterized by slower cycling speeds, suggesting the absence of a dedicated bike path or an increase in interaction with traffic signals and pedestrian crossings. In particular, at **"Via Carlo Prina, Via Borigazzi, and Via Buonarroti"** absence of infrastructure is observed, resulting in low speeds. Peripheral routes exhibit more consistent and higher speeds, indicating smoother movement conditions compared to the central core.

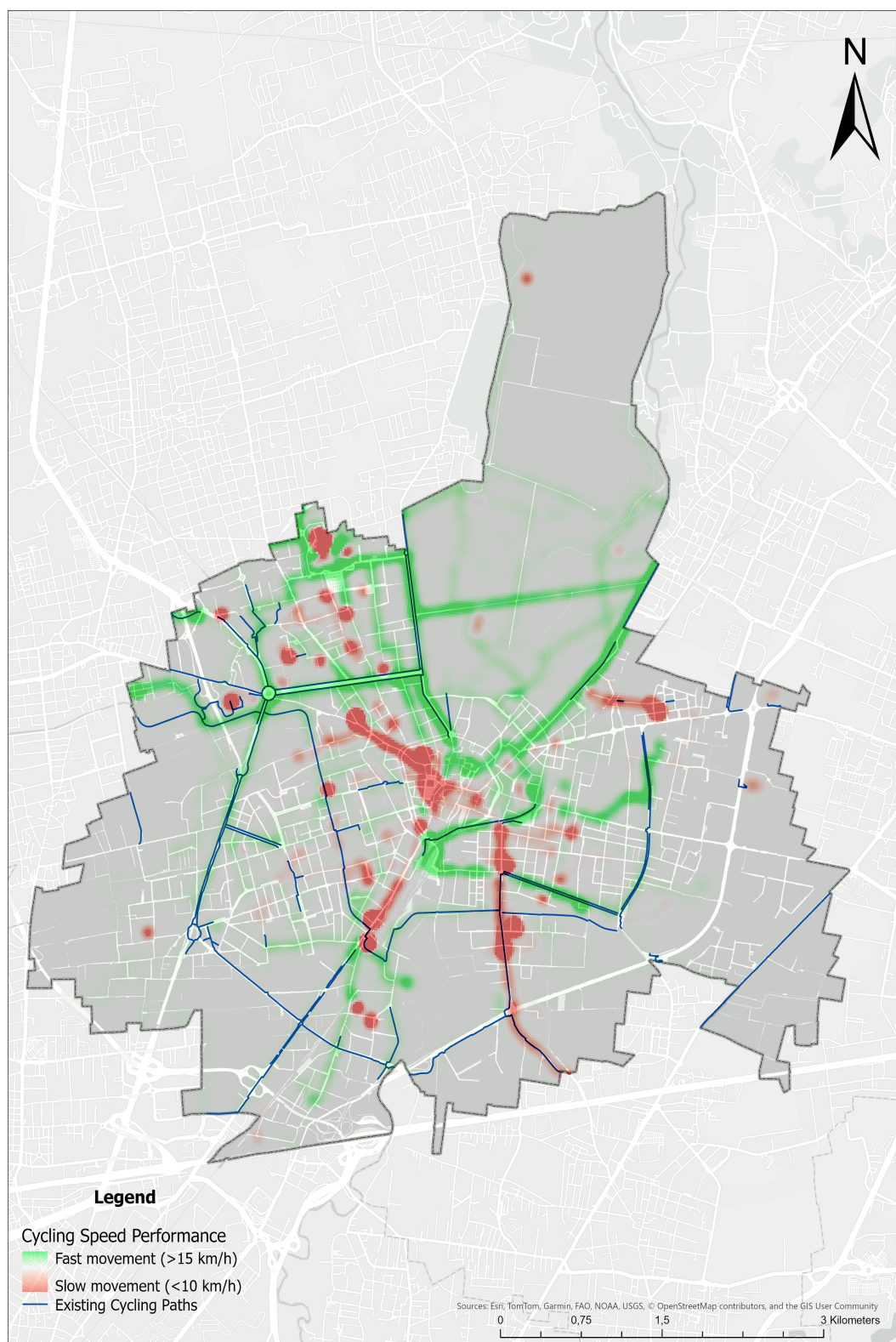


Figure 5.4: Fast and Slow corridors with Existing Infrastructure

The comparison of speed-based kernel density analysis with the existing cycling infrastructure layer enables the identification of areas where infrastructure provision supports efficient movement, as well as areas where performance is constrained despite the presence of cycling paths. The results indicate that several central areas of Monza exhibit low cycling speeds despite high levels of activity, and also the absence of bike infrastructure. This suggests that factors such as intersection density, traffic interactions, and urban complexity affect cycling performance. These locations represent priority zones for infrastructure development. The analysis helps to identify both well-performing corridors and critical areas where improvements in continuity, intersection design, or route protection may be needed.

5.1.4. Origins & Destinations of Commuters

The Origin-destination analysis is important to understand where the trips begin and where they end in the morning and evening rush hours, and to examine whether they follow any clear commuting structure. It helps to identify the main areas of trip generation and the attractions within the study area. The origin and destination points were then mapped separately in ArcGIS Pro to examine their spatial distribution across the study area. Since the analysis refers to employees commuting and focuses on the rush hours, the identified origins can be interpreted as the participants' residential areas, while the destinations likely correspond to workplaces and other office-related locations.

Trips Originated at Morning Rush Hours

Here, the GPS trajectory dataset was filtered to include only trips recorded during the morning rush-hour period (07:30-08:30). The morning rush hours are important for commuters because they represent the main trip from home to work, making them linked to regular commuting patterns more than the evening period, which may include more varied return trips and other activities. For each trip session, the first recorded point was extracted as the origin, using the timestamp information available in the dataset.

The spatial distribution of trip origins, where individual points represent the starting locations of cycling trips during the morning rush hours. The origin points are distributed throughout multiple residential zones, particularly in the southern, western, and eastern parts of Monza. While some concentration is observed near the central area, the overall pattern indicates that trips originate from a wide range of neighborhoods. Some trip origins are also located outside the Monza study area, suggesting that a small share of employees commute by bicycle from neighbouring areas into Monza.

A dispersed pattern of these trip origins supports equal levels of infrastructure development by identifying multiple neighborhoods with cycling demand, enabling planners to design a more connected and inclusive cycling network in the City.

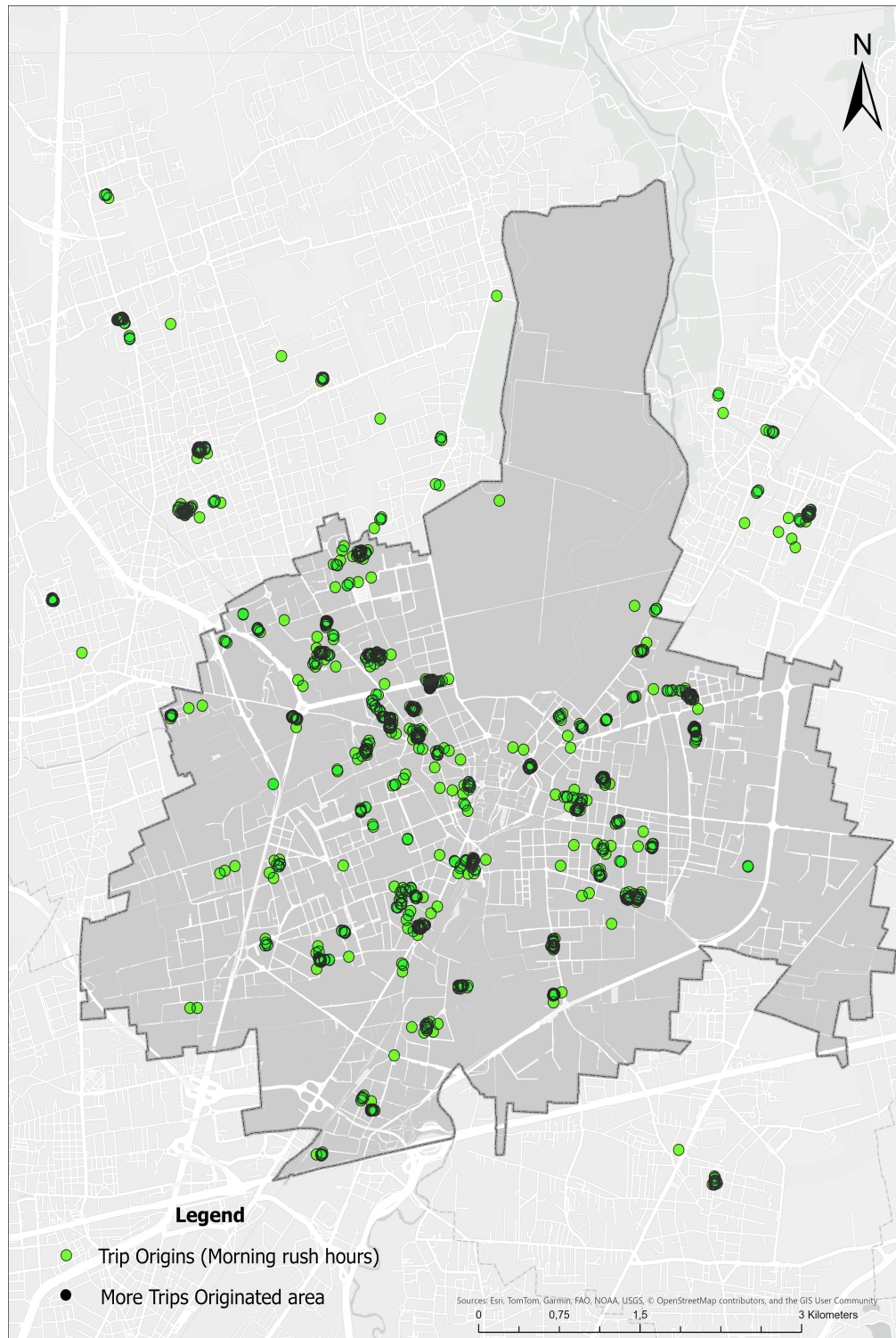


Figure 5.5: Trip Origins at Morning Rush Hours

The figure below represents a clustered visualization of the morning rush hour origins. Clustering was performed in Arc GIS Pro using the built-in aggregation tool, which groups nearby points within a specified spatial radius. Each cluster represents the total number of trips aggregated within the area, and the displayed number indicates how many trips are aggregated within the cluster. Larger and darker clusters correspond to areas with higher concentrations of trip origins.

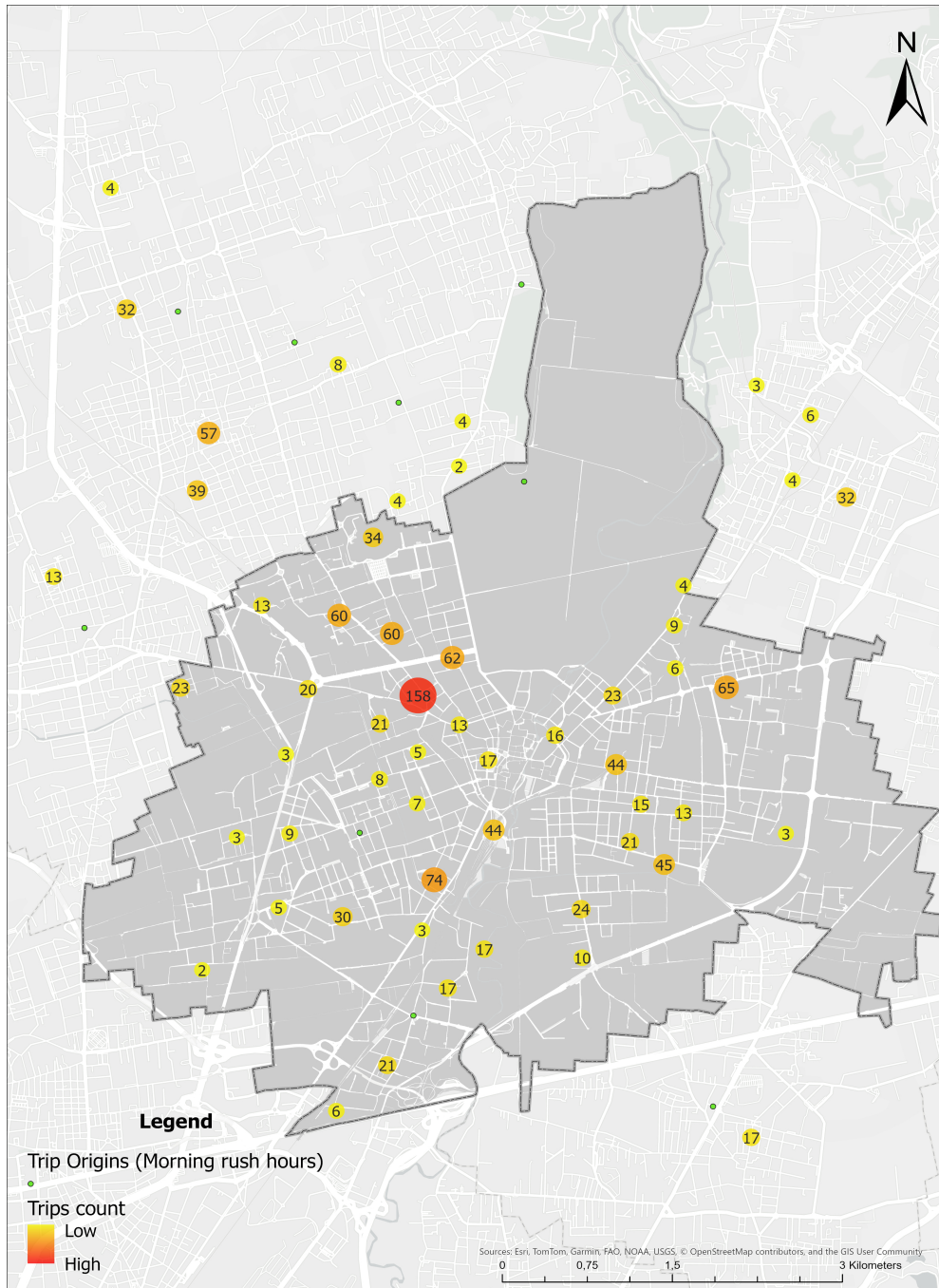


Figure 5.6: Clustering of Origins at Morning Rush Hours

Trips Attracted at Morning Rush Hours

The spatial distribution of trip destinations shows that during the morning rush hours, the destinations are less dispersed, unlike the origin pattern, and show a clear concentration in a limited number of areas. For each trip session, the last recorded point was considered as the destination, using the timestamp information available in the dataset.

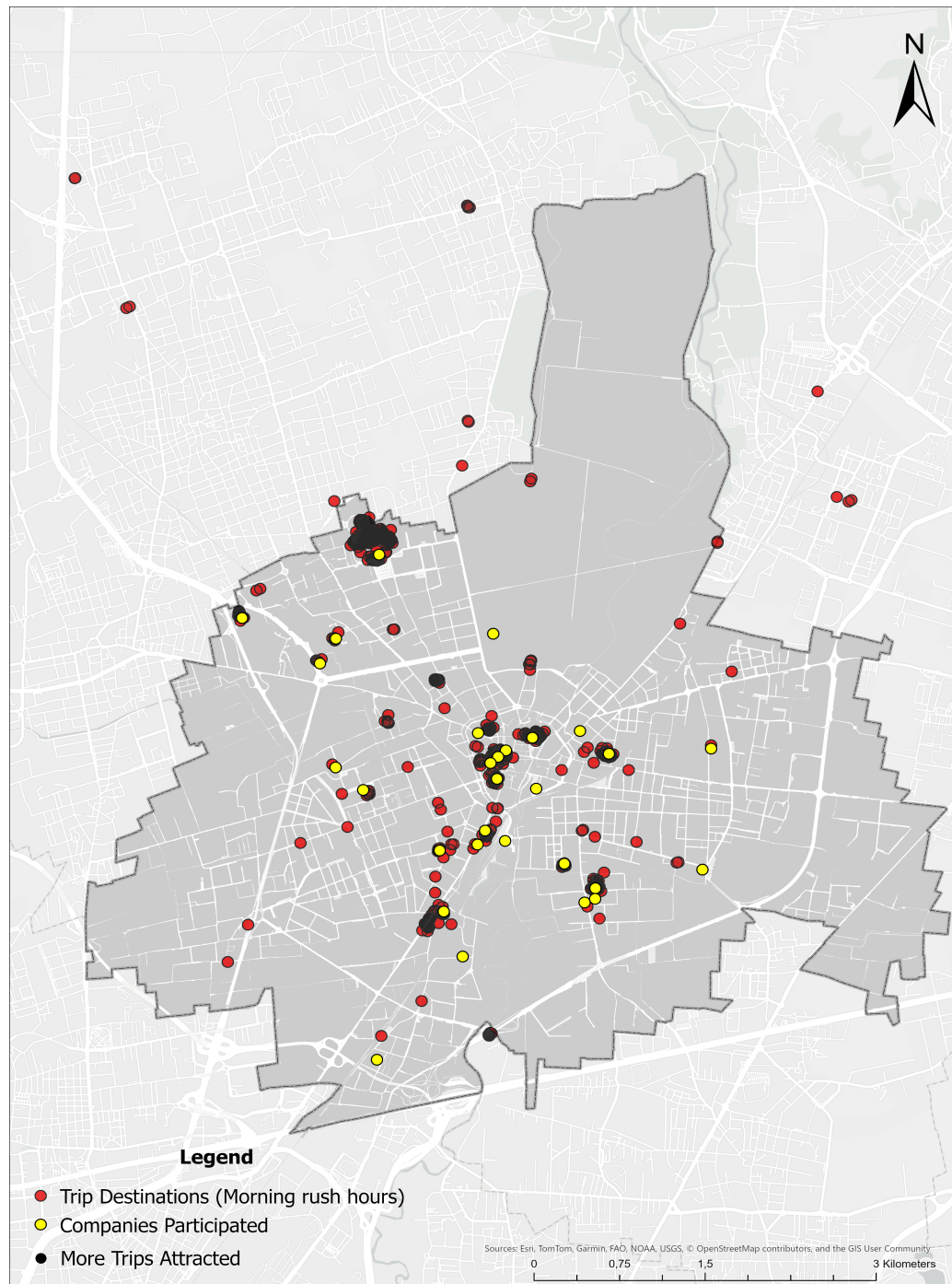


Figure 5.7: Trip Attracted at Morning rush hours

The strongest cluster from the following figure appears in the central part of Monza and is associated with the main Municipality building of Monza, while a second cluster is near the San Gerardo Hospital. The smaller clusters correspond to the other company locations involved in the Pilot GreenPATH Monza. This pattern suggests that morning bicycle trips are mainly attracted to key employment-related locations rather than being evenly distributed across the city. From a spatial planning perspective, this result helps to identify the locations where cycling access paths may be most important during the morning commuting period.

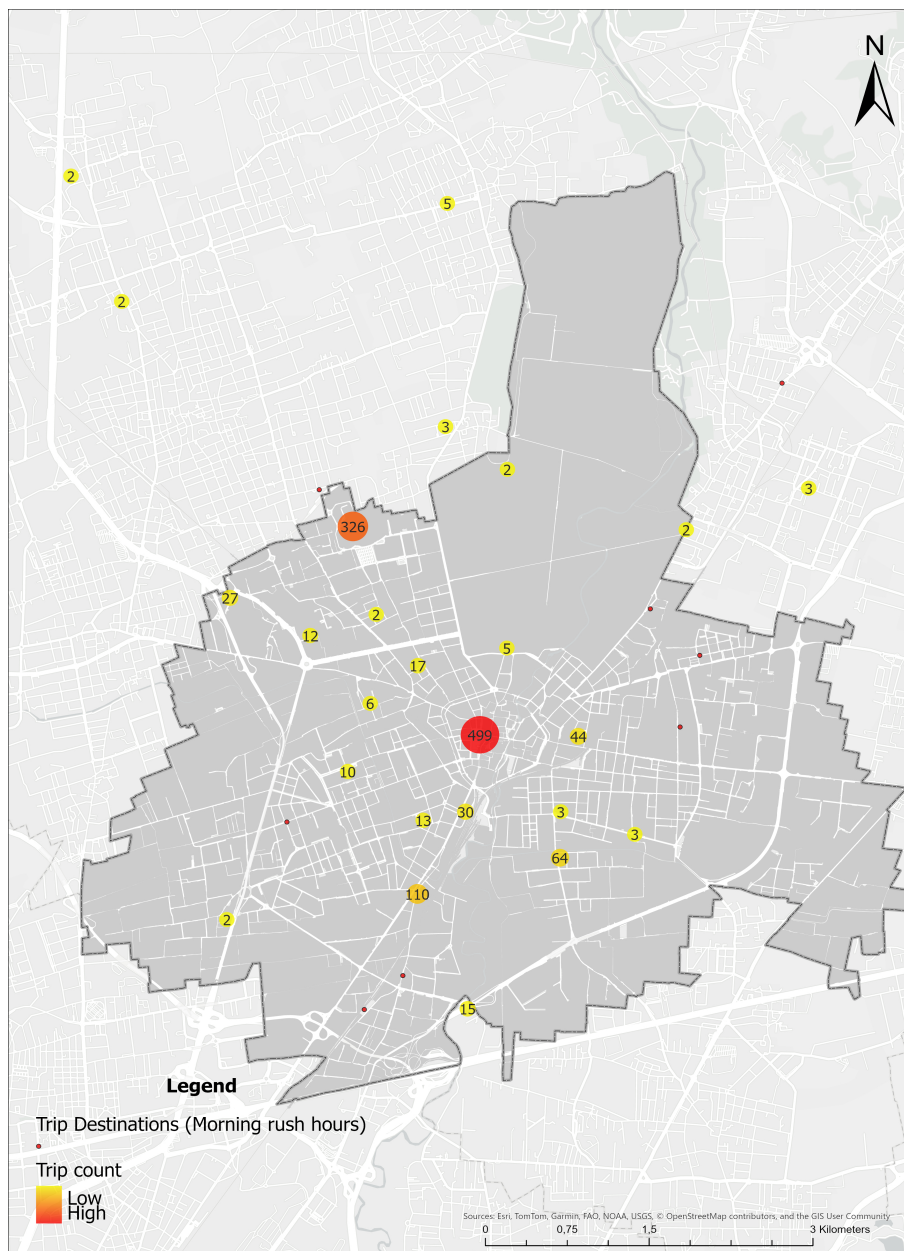


Figure 5.8: Clustering of Destinations at Morning Rush Hours

Trips at Evening Rush Hours

The evening rush-hour maps show a different pattern from the morning commuting pattern. In the evening period, trip origins are more concentrated in the main employment-related areas, around the city center, at the Municipality of Monza, and the San Gerardo Hospital on the northern side, which is consistent with workers leaving their workplaces at the end of the day.

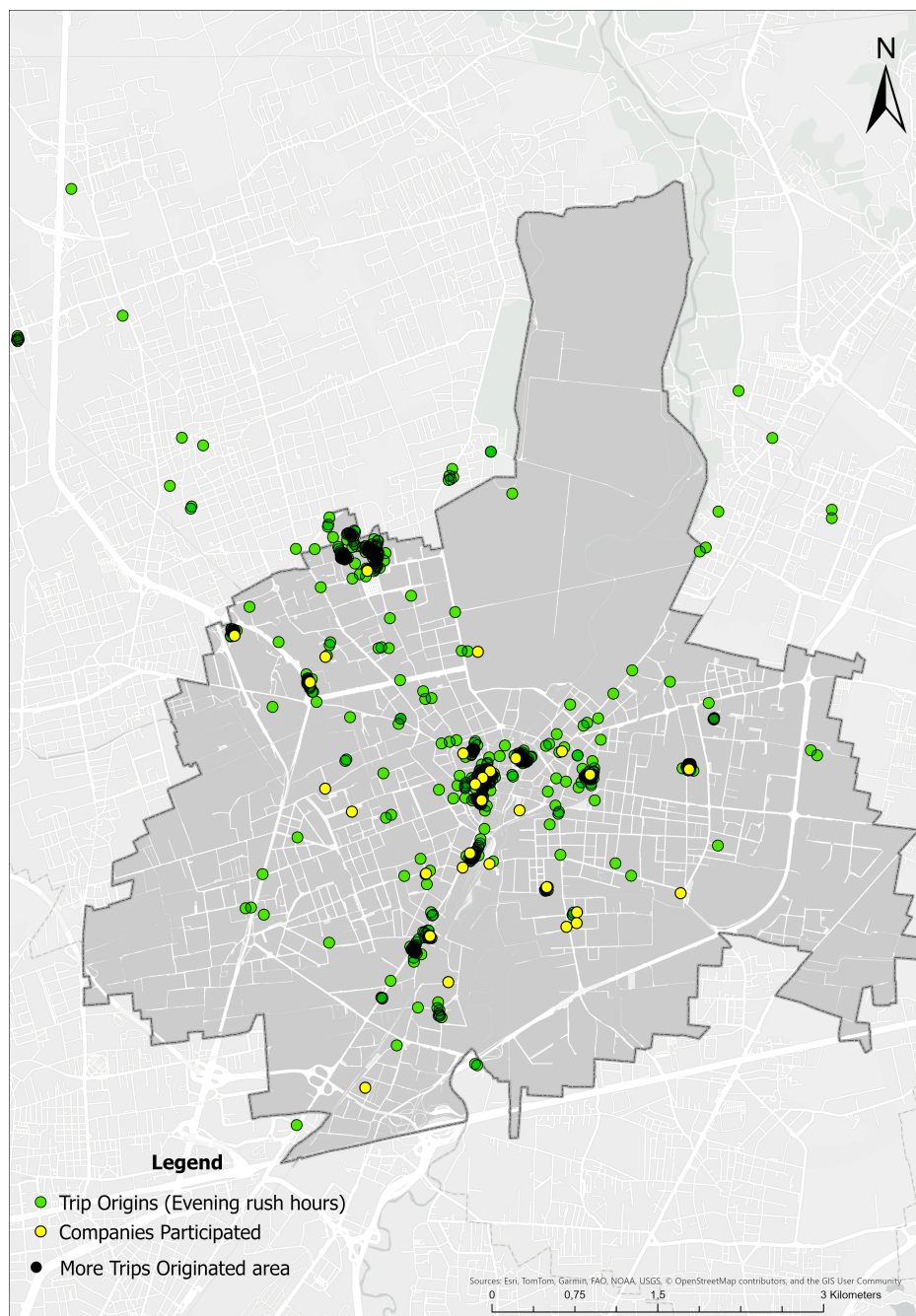


Figure 5.9: Trip Origins at Evening rush hours

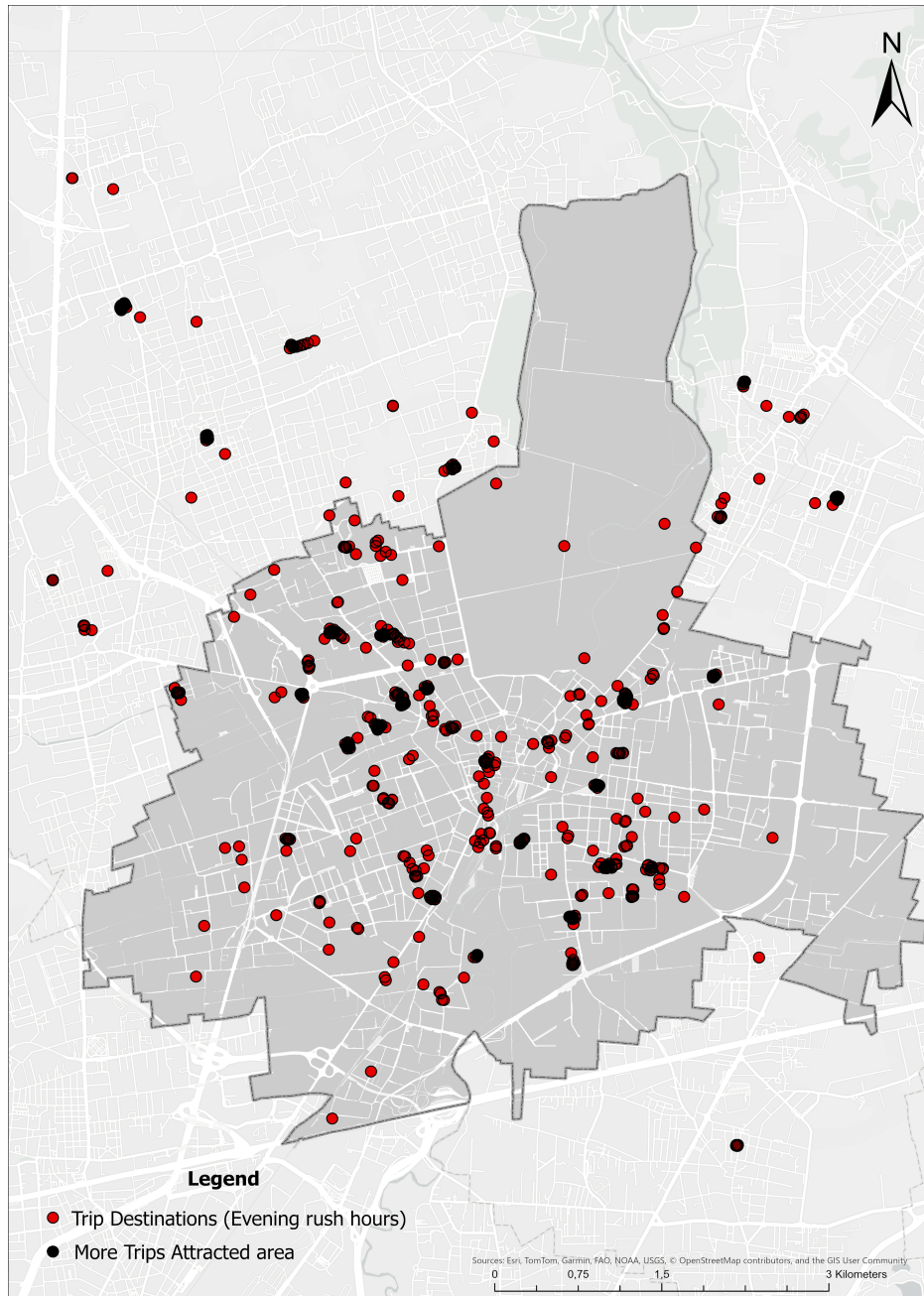


Figure 5.10: Trip Destinations at Evening rush hours

Trip destinations are more dispersed across the study area, suggesting that cyclists may return to their home locations. A few destinations are also visible outside the Monza study area, which may indicate that some employees return to neighbouring municipalities after work. This reversal between the morning and evening patterns is meaningful, as it confirms a regular home-to-work and work-to-home structure in the observed bicycle trips. While the morning movements are mainly directed toward key work attractors, the evening movements appear more outward and spatially distributed.

5.2. Descriptive Analysis of Survey

This section is organised according to the five survey modules used in the app-based questionnaire. Each module focuses on a different aspect of the commuting experience and helps build a structured understanding of bicycle use during the GreenPATH Monza pilot.

5.2.1. Module 1 – Company HQ Infrastructure and Facilities

The module 1 results focus on three main aspects: The availability of bicycle parking and the type of bicycle parking at the company headquarters, the presence of cycling-related support services, and whether the workplace is connected to a protected cycling path.



Figure 5.11: Parking availability

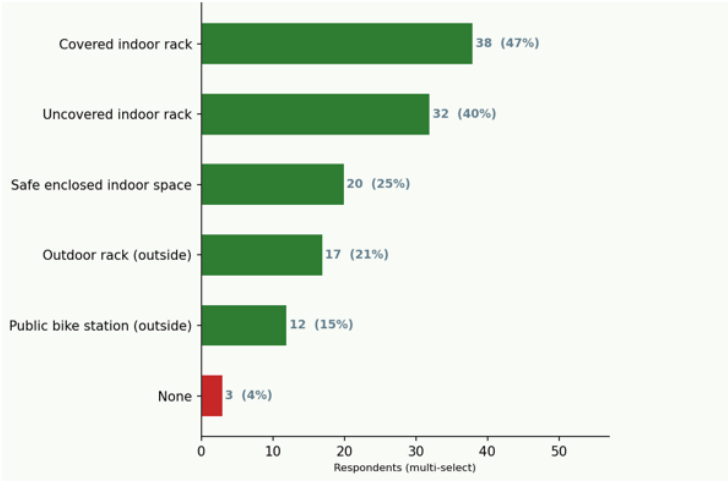


Figure 5.12: Types of Bike Parking

For the availability of bicycle parking, out of 81 respondents, 96% reported the presence of some form of bicycle parking, while only 4% reported that no parking is available. Parking is available for most respondents in the city of Monza. Parking is the most basic requirement for bicycle commuting. But having some type of parking doesn't meet the satisfaction or security levels of bicycle users. Looking more closely at the type of parking available, the most common option is the covered indoor rack, reported by 38 respondents (47%), followed by the uncovered indoor rack, mentioned by 32 respondents (40%). A safe enclosed indoor space is reported by 20 respondents (25%), while outdoor racks are reported by 17 respondents (21%). The least common parking type among the available options is the public bike station outside the company premises, reported by 12 respondents (15%). These values indicate that some workplaces provide more than one parking option. As not all parking facilities offer the same quality of support, covered or

indoor racks generally provide a better level of protection from weather and may improve the perceived convenience of commuting by bicycle. Safe enclosed spaces can further strengthen security, although they are available only to a quarter of respondents. The outdoor racks and public stations, while useful, may provide lower perceived security or convenience depending on their design and location. These results help to assess how supportive the destination environment is for daily bicycle commuting. Therefore, the results suggest that workplace bicycle parking in Monza is not only widespread but is often provided in forms that can be considered relatively supportive of commuting, in the case of indoor and covered solutions.

Available Services at Company:

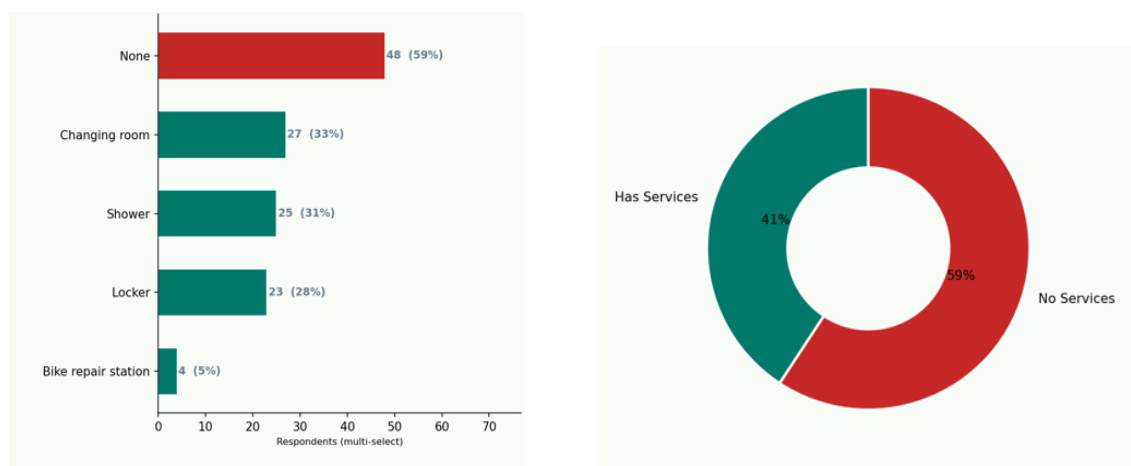


Figure 5.13: Services at Company

The second main result concerns the availability of cycling-related services at the workplace. In contrast to parking, support services appear much less developed. It shows that 48 respondents (59%) report no cycling-related services at all. Conversely, only 41% of respondents indicate the presence of at least one service. Among the specific facilities, the most frequently reported is the changing room, available to 27 respondents (33%). This is followed by showers, reported by 25 respondents (31%), and lockers, reported by 23 respondents (28%). The least available service is the bike repair station, mentioned by only 4 respondents (5%). Most workplaces provide parking, fewer provide the complementary facilities that make everyday cycling easier and more comfortable, especially for employees commuting in work clothes, over longer distances, or in variable weather conditions. Changing rooms, showers, and lockers can help normalize bicycle commuting within the workplace environment as they reduce inconvenience and improve the transition between commuting and work activities.

Access to Protected Path:

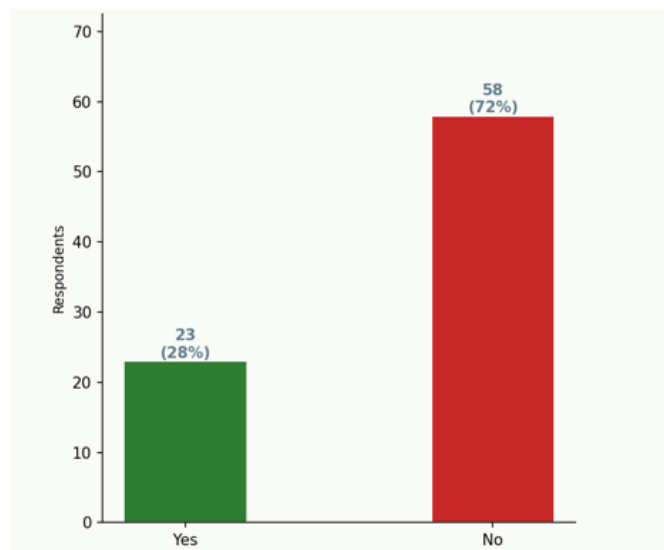


Figure 5.14: Protected Bike Path

The protected path provides access to the workplace, measured through the presence or absence of a protected cycling path leading to the company headquarters. Only 23 respondents (28%) report that their headquarters are on a protected path, while 58 respondents (72%) report that they are not. This indicates that most respondents reach workplaces that are not directly served by protected cycling infrastructure. The employees may perceive cycling as unsafe, which may significantly affect their willingness to use a bicycle regularly. From a planning perspective, cycling to become a stronger and more attractive commuting option for employees, greater attention should be given to showers, changing rooms, lockers, and more importance should be given to connecting the workplaces with protected cycling routes.

5.2.2. Module 2 – Route Preferences in Monza

The module 2 results focus on the spatial preferences of 65 respondents regarding cycling infrastructure in Monza. The first result regarding the question “Where to build the next bike path?”

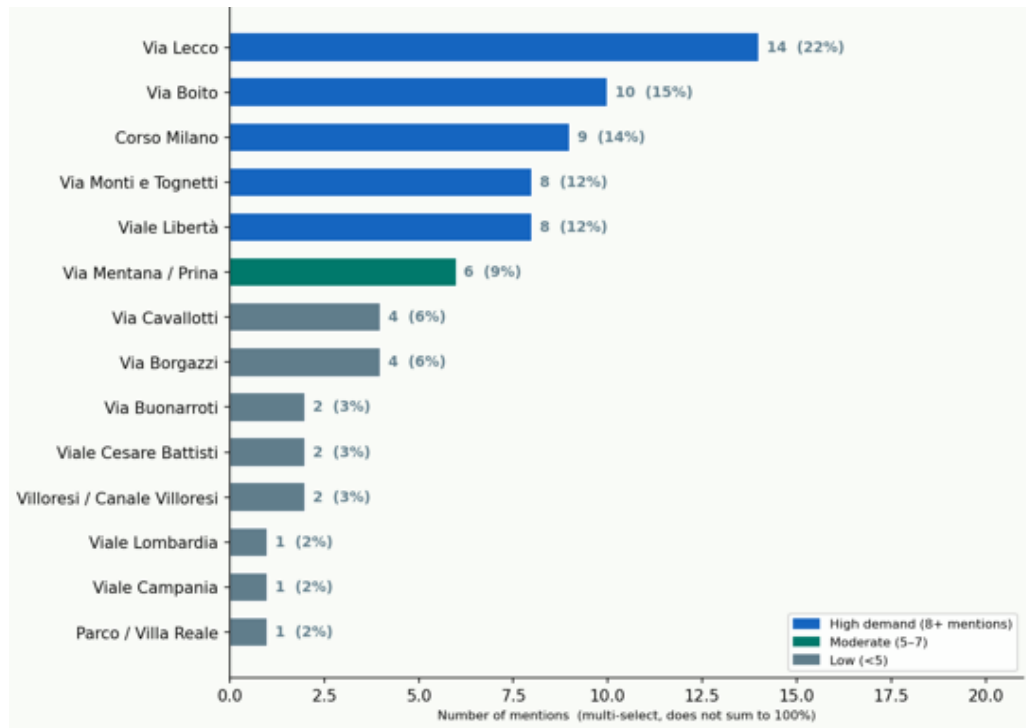


Figure 5.15: Preferences for future cycle path

The responses indicate that participants can identify specific missing links in the cycling network. The route receiving the highest number of mentions is Via Lecco, selected by 14 respondents (22%). This is followed by Via Boito, with 10 mentions (15%), and Corso Milano, with 9 mentions (14%). Two further routes, Via Monti e Tognetti and Viale Libertà, each receive 8 mentions (12%), and others with less mentions. It shows that the demand for new cycling infrastructure is not evenly spread across the city. Instead, users point towards a group of corridors where they perceive a stronger need for intervention. Via Lecco is suggested as an important missing element in the network, either because it lacks sufficient cycling infrastructure or because it requires improving continuity.

The spatial representation helps locate the corridors where demand for new cycling paths is concentrated within the existing network of Monza.

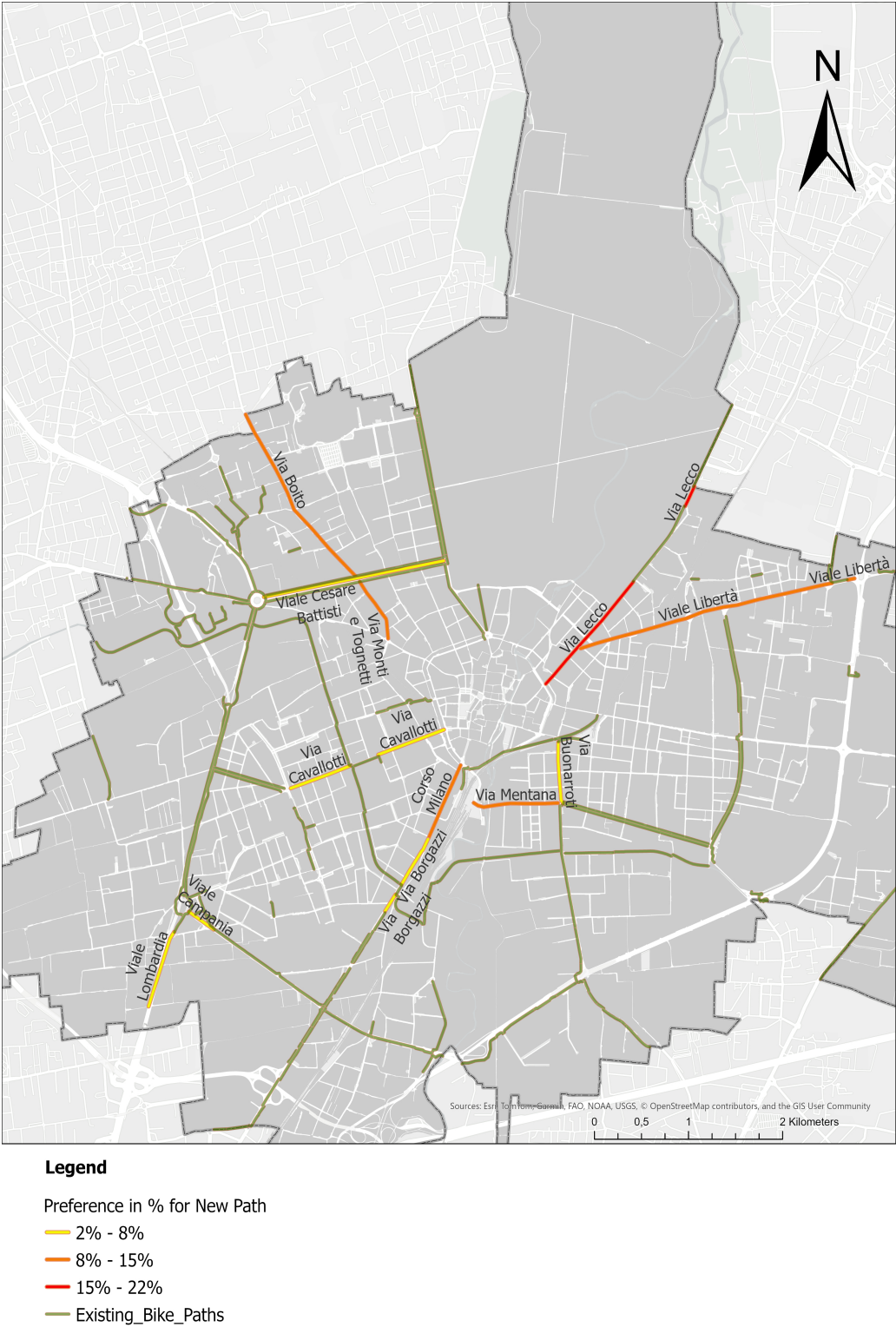


Figure 5.16: Preferred Routes for New Cycling Paths

Preferences for Path Improvement:

The second result concerns the question “Which existing path should be redeveloped?” The responses show that a limited set of routes attracts the highest level of attention. The most frequently mentioned corridor is Via Borgazzi, selected by 9 respondents (14%). It is followed by Villa Reale, with 8 mentions (12%), and then by Villoresi / Canale Villoresi and Via Lecco, each with 6 mentions (9%). Viale Cesare Battisti received 5 mentions (8%), while Viale Campania was selected by 4 respondents (6%).

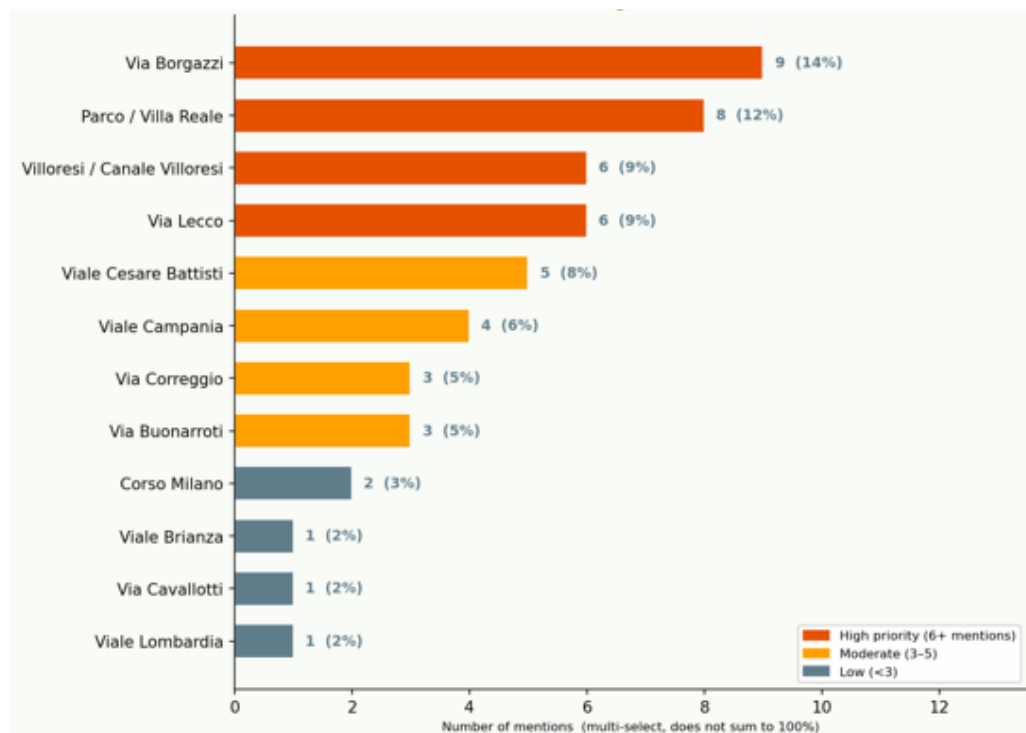
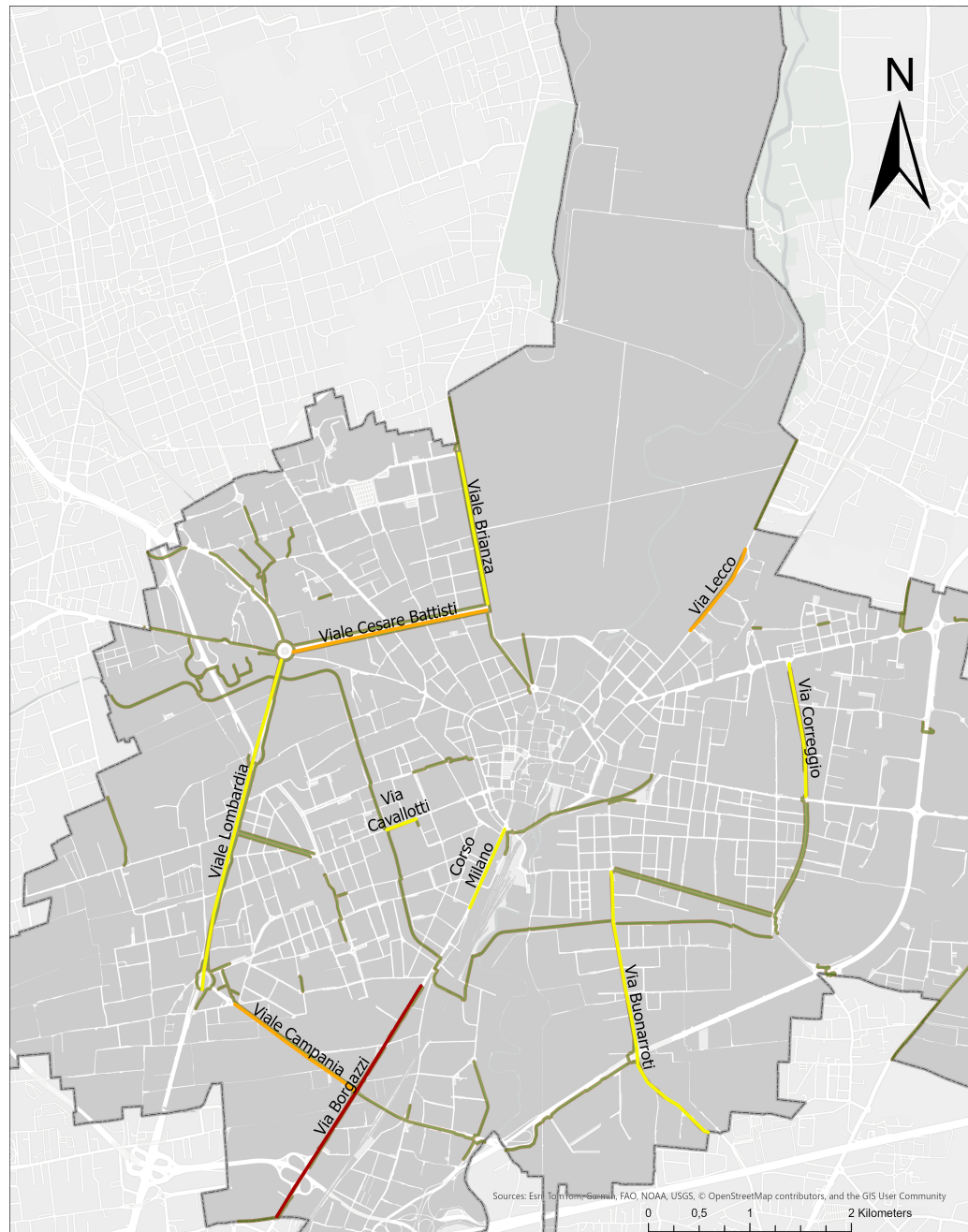


Figure 5.17: Preferences for Bike path redevelopment

The participants are not concerned only with building new cycling paths, but also with improving parts of the network that already exist but are not working well enough. The routes identified for redevelopment can be understood as corridors where cycling infrastructure is present, but its current condition may not be adequate for everyday use. The responses point to strengthening the existing network through expansion of the network. From a planning point of view, redevelopment of existing routes may produce faster and more direct benefits than building new infrastructure. Improving continuity, pavement quality, protection from traffic, and the clarity of the route along these corridors could make the current cycling network more usable and more reliable for daily commuting.

The routes identified in the survey were also represented spatially to show how preferences for redevelopment are distributed across the city.

**Legend**

Preference in % for Redevelopment

— 2% - 5%

— 5% - 9%

— 9% - 14%

— Existing_Bike_Paths

Figure 5.18: Routes Identified for Redevelopment

Favourite Bike Paths in Network:

For favourite bike paths, the responses show that Villoresi / Canale Villoresi as most favourite route selected by 24 respondents (37%). This makes it by far the most appreciated cycling corridor in the sample. The second most favourite route is Viale Cesare Battisti, with 10 mentions (15%), followed by Viale Lombardia with 6 mentions (9%), and Viale Brianza with 5 mentions (8%), and other routes are less preferred.

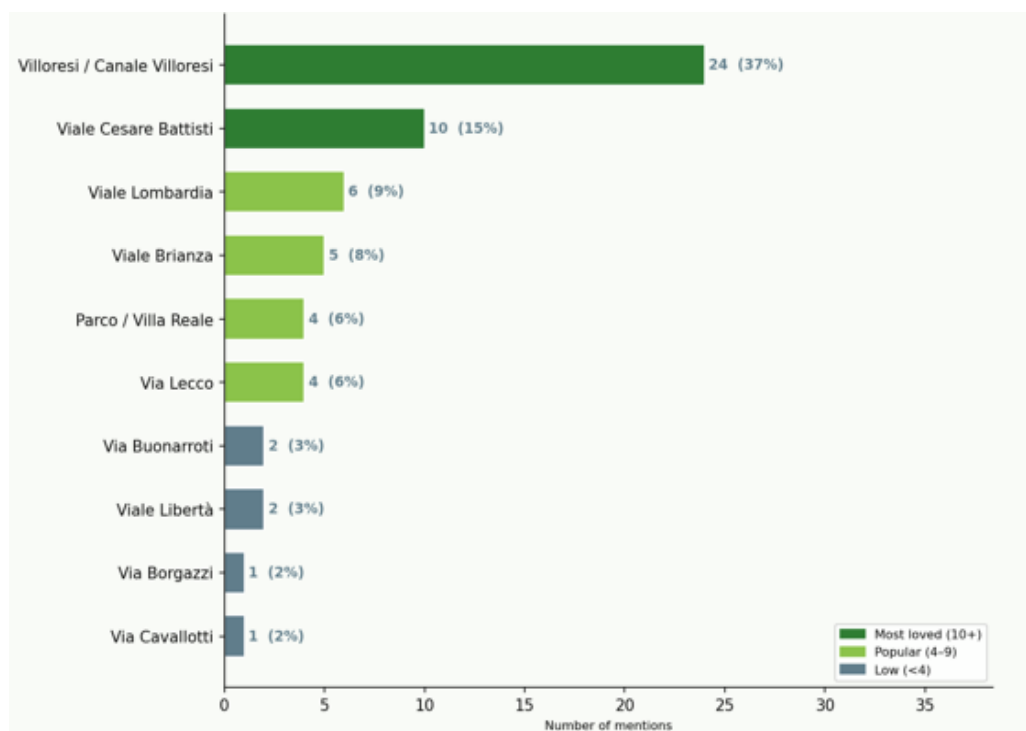


Figure 5.19: Favourite Bike Paths

From the Pie chart representation regarding the favourite routes, Villoresi / Canale Villoresi stands with 41% of the top five route share, while Viale Cesare Battisti represents 17%, Viale Lombardia 10%, Viale Brianza 8%, and Via Lecco 7%. The remaining 17% is grouped under “other routes.”

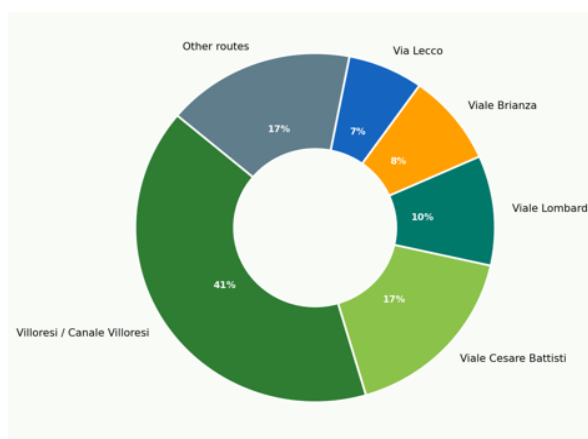


Figure 5.20: Favourite Bike Paths - Pie chart

A route such as Villoresi / Canale Villoresi may be expressed as a favourite route for reasons such as continuity, safety, attractiveness, or comfort, even as those dimensions are not measured directly in this module. It provides examples of the kinds of corridors that are experienced as more successful by cyclists.

When considering together, "Via Lecco" is selected as the next bike path to build and is mentioned as one of the routes for redevelopment, maybe because the network is fragmented and the existing path in Via Lecco may still require improvement in quality, continuity, or safety. In the same way, Villoresi / Canale Villoresi is both the favourite route and one of the corridors identified for redevelopment, indicating that even well-liked corridors may further need improvement.

These results can support the municipality in prioritising interventions that respond to actual cycling demand and perceived network gaps, even if the targeted interventions on a limited set of routes could improve the perceived usability and continuity of the cycling network in Monza.

5.2.3. Module 3 – Obstacles to Cycling

The main difficulties that discourage bicycle use, transport modes considered when cycling is not used, and the travel time compared with the usual mode are focused on this module. The results are useful as they show both the negative factors that limit cycling. The two most important barriers are the absence of a cycle lane on the route and bad weather, each selected by 32 respondents (67%) in a total of 48 responses. These two factors stand out from the others and can be considered the dominant barriers in the sample. It shows that bicycle commuting is influenced both by infrastructure conditions and by external environmental conditions. The lack of a dedicated bike lane directly affects the possibility of riding safely and comfortably. On the other hand, weather conditions remain as a factor that can reduce the regularity of cycling. The next most identified barrier for cycling is perceived danger, selected by 17 respondents (35%), while the lack of cycle lanes refers to a physical infrastructure problem; perceived danger reflects the feeling of risk associated with cycling in traffic.

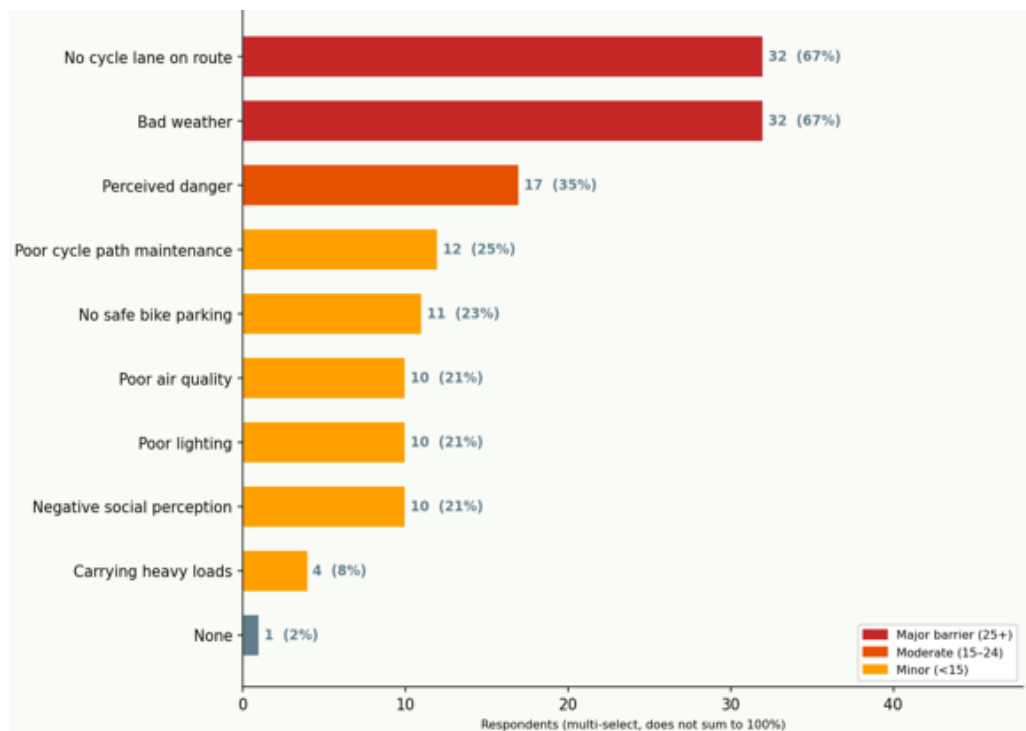


Figure 5.21: Obstacles to Bike

The results show that the cycling experience is influenced not only by what infrastructure exists, but also by how safe the route feels to users. The other less dominant barriers are Poor cycle path maintenance selected by 12 respondents (25%), and no safe bike parking by 11 respondents (23%). These factors are less dominant than the first two barriers and indicate both the quality of the cycling network and the quality of destination support. Poor maintenance may refer to pavement condition, surface irregularities, or lack of cleaning, all of which can reduce comfort and safety.

Three other barriers are each selected by 10 respondents (21%): poor air quality, poor lighting, and negative social perception. Poor air quality suggests that the environmental conditions of the city may discourage active mobility on roads with heavy traffic. Poor lighting is likely associated with route security and visibility during late hours or winter months. Negative social perception may indicate that cycling is not yet fully normalised or socially encouraged in all commuting contexts. This suggests that the cycling experience also depends on cultural factors.

For the identified barriers, several targeted interventions can be considered. The most impactful measure would be the "development of a connected and protected cycle lane network", which would directly address both the absence of dedicated infrastructure and the perceived danger reported by respondents. Improving the maintenance of existing

cycle paths and expanding secure bike parking at key destinations would further reduce obstacles to cycling. To mitigate the effect of bad weather, covered cycling facilities and weather-resistant route surfaces could be encouraged. Poor air quality and inadequate lighting can be addressed through route planning that prioritises low-traffic roads and the installation of adequate street lighting along cycling corridors. Finally, overcoming negative social perception requires awareness campaigns and employer-supported cycling incentives that normalise cycling as a mode of urban commuting.

Alternative Modes when not Cycling:

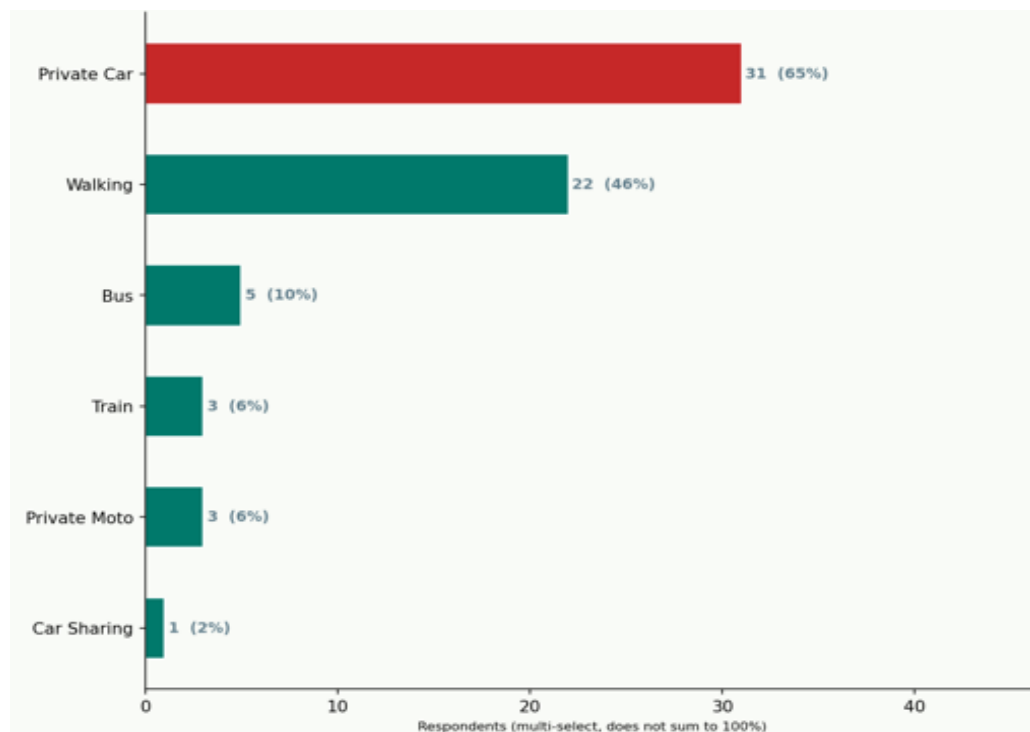


Figure 5.22: Alternative Transport Modes

For the transport mode used when the user is not cycling, the results show that the most common alternative is the private car, used by 31 respondents (65%), and walking is reported by 22 respondents (46%). Other transport modes appear much less frequently; bus is mentioned by 5 respondents (10%), train by 3 respondents (6%), private motorbike by 3 respondents (6%), and car sharing by only 1 respondent (2%). Here, the private car remains the dominant option when cycling is not chosen. The second relatively high presence of walking suggests that the many trips fall within distances to be made on foot. The low use of buses, trains, and shared mobility indicates that public or shared alternatives are much less relevant than private modes in the reported behaviour.

Therefore, any increase in cycling could represent a shift away from private motorised use, which is acceptable from the point of view of congestion, emissions, and sustainable mobility policy.

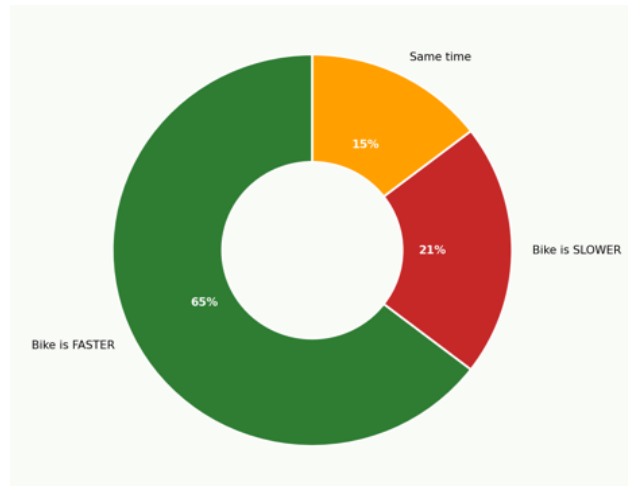


Figure 5.23: Travel Time efficiency of Cycling

Travel time is one of the main conditions for a mode to become attractive. Many participants perceive cycling as faster than their usual transport, suggesting that bicycle commuting is an advantage for users. If users perceive cycling as time-efficient, they are more likely to consider it not only as a sustainable option but also as a convenient one. There is a presence of a smaller group reporting that the bicycle is slower; the variation may depend on trip distance, route quality, traffic conditions, or travel habits. Considering all responses together, the cycling in Monza appeared to have an advantage in terms of travel time, but is stopped by infrastructure and safety-related barriers. This means prioritising safer and more continuous cycling routes, improving maintenance and lighting, could shift commuting by bike.

5.2.4. Module 4 – Travel habits before and during the pilot

This module examines how participants' travel habits, such as daily spending, daily distance traveled, and commute time, changed before the pilot and during the pilot period.

Pre-Pilot Travel Mode:

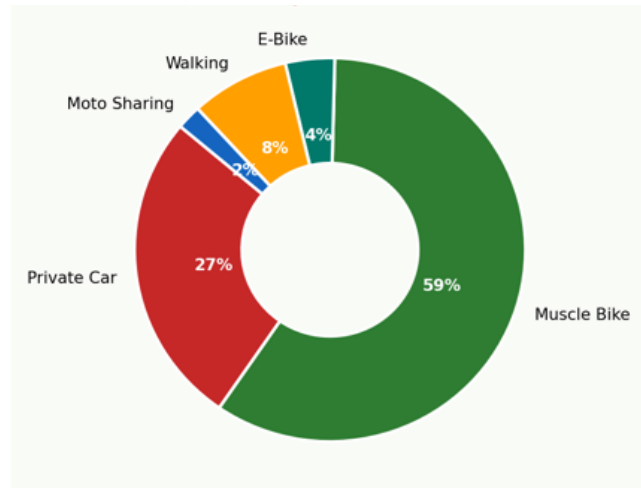


Figure 5.24: Transport mode before Pilot

The distribution shows that the largest share of respondents are already users of a bike, representing 59% of the sample. The private car, used by 27% of respondents. Smaller shares are reported for walking (8%), e-bike (4%), and moto sharing (2%). This result says that part of the sample already had some connection to bicycle use before the pilot. A portion of the participants were using a less sustainable transport mode and therefore had the potential to shift toward bicycle commuting during the pilot.

Travel Time Comparison:

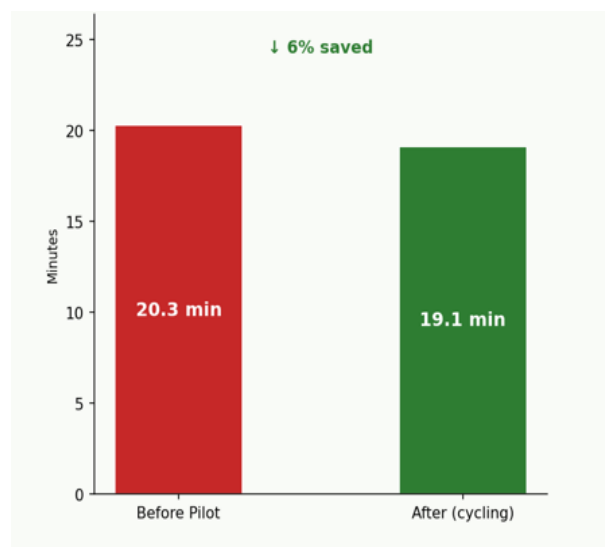


Figure 5.25: Comparison of Travel time

The second result regarding commute time before and during the pilot. The average commute time before the pilot is 20.3 minutes, while the average time during the pilot decreases to 19.1 minutes. This corresponds to a reduction of 6%. Although the difference is not very large, it is still meaningful because commuting time is one of the most important attributes in daily travel decisions.

Travel Cost Comparison:

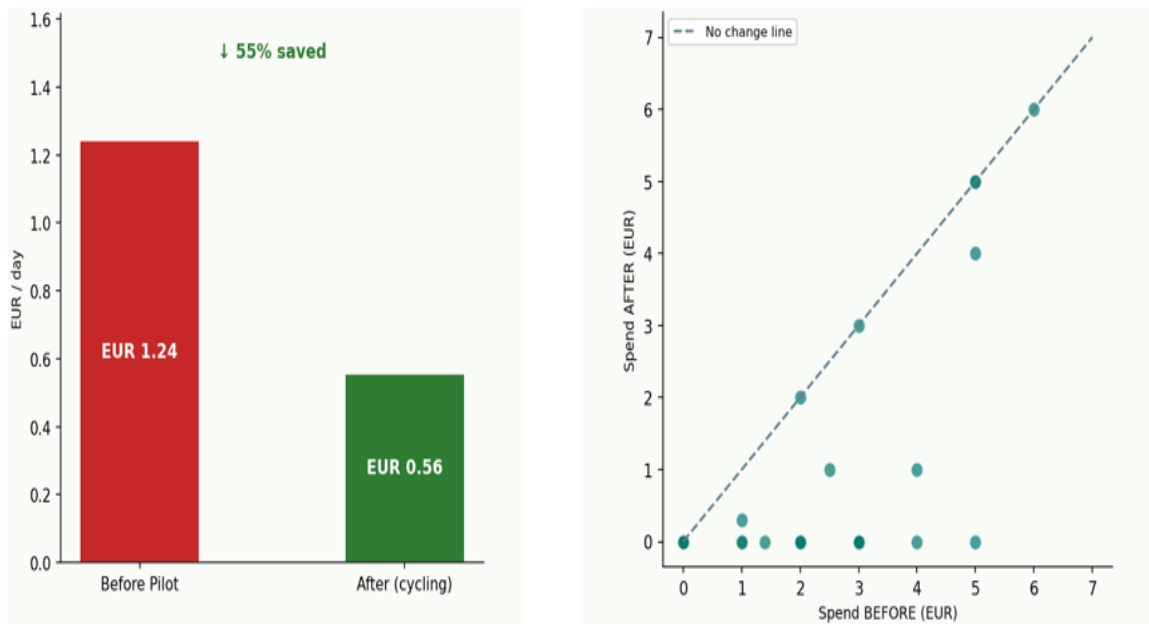


Figure 5.26: Comparison of Travel Cost

Commuting costs are a major factor affecting daily mobility choices. The scatter plot of spending per person before and after the pilot shows that most observations lie below the diagonal “no change” line, meaning that most respondents spent less during the pilot than before it. Several participants even report spending close to zero after shifting to cycling. This pattern shows that the cost reduction is shared by a large part of the sample, which means that cycling is not only perceived as sustainable but also as economically beneficial.

Travel Distance Comparison:

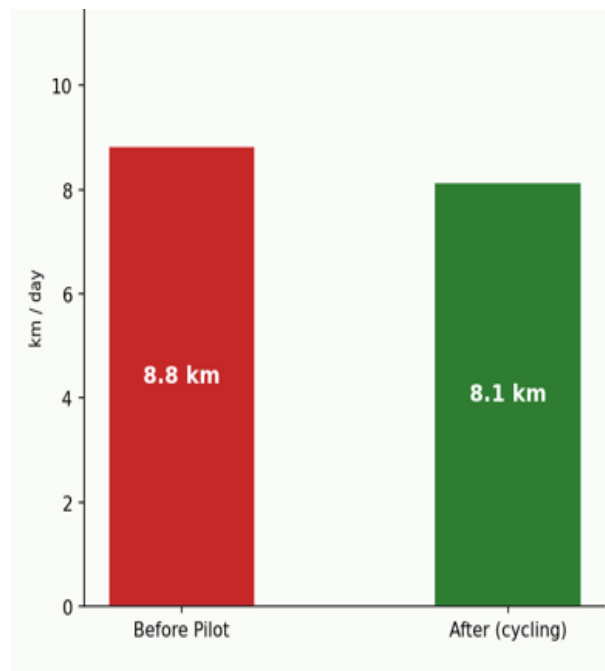


Figure 5.27: Comparison of Travel Distance

The fourth result concerns daily distance travelled. The average distance before the pilot is 8.8 km/day, while during the pilot, it becomes 8.1 km/day, indicating a slight reduction in travelled distance. If the distance had dropped more, then the reduction in time and cost might have been because of shorter trips rather than Cycling. Overall, Module 4 shows that the GreenPATH Monza pilot is associated with improvements in everyday commuting. Commute time became shorter, daily spending decreased, and the distances travelled remain comparable. These findings suggest that bicycle commuting during the pilot was economical, in addition to its sustainability value.

5.2.5. Module 5 – Satisfaction and Feedback: Before vs During the Pilot

This module evaluates the commuting experience before and during the pilot, focusing on four perceptions: Overall satisfaction, speed and convenience, stress, and safety.

Change in Commuting Stress:

In daily commuting, stress can come from congestion, delays, and interactions with traffic. Here, the mean stress score decreases from 3.00 before the pilot to 2.50 during the pilot, corresponding to a change of -0.50 points. The lower the value, represents a better the outcome. Bicycle commuting during the pilot was associated with a less stressful experience for many participants because, compared with motorized or public transport commuting, cycling may have offered a more predictable trip, with less interruptions, less waiting, and a greater sense of personal control over the journey.

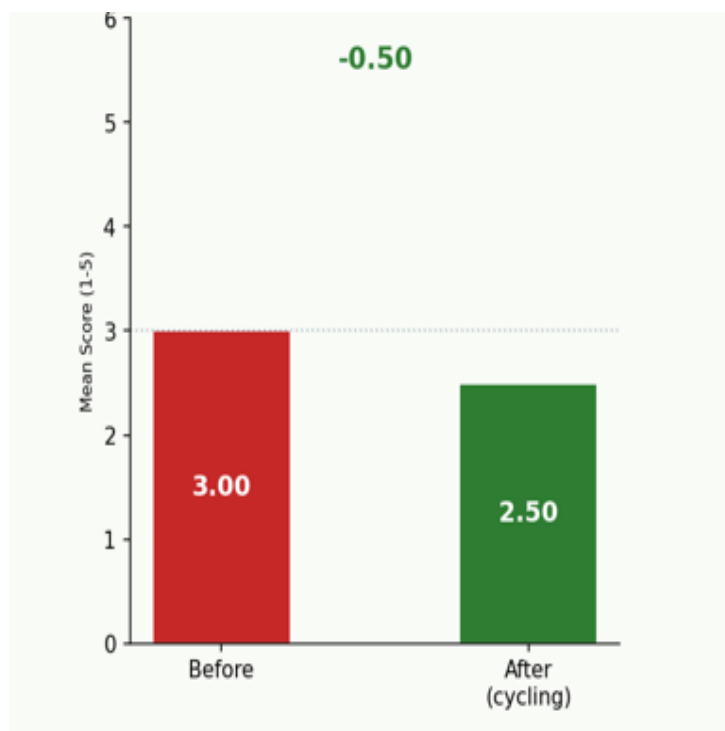


Figure 5.28: Stress Score

Change in Safety Perception:

The mean safety decreased from 3.24 before the pilot to 2.82 during the pilot, corresponding to a change of -0.41 points.

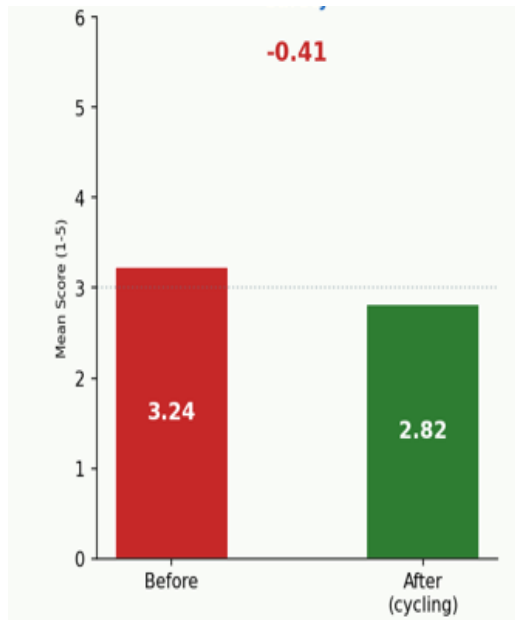


Figure 5.29: Safety Score

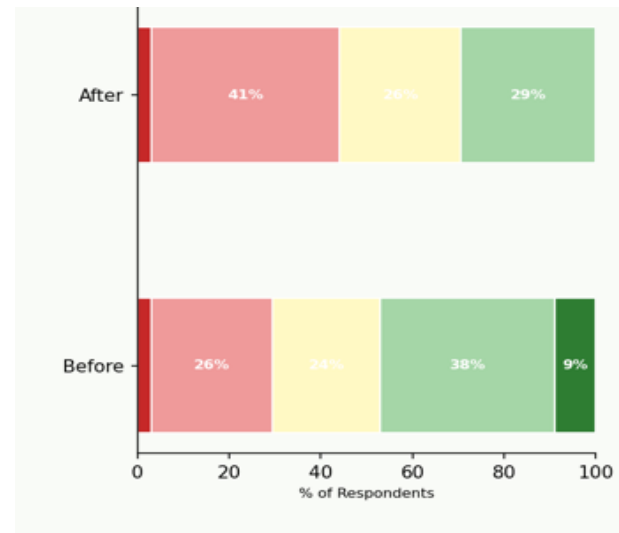


Figure 5.30: Distribution of Safety

From the distribution of safety scores, 38% of respondents chose 4, 24% chose 3, 26% chose 2, and 9% chose the top score of 5 before the pilot. The pattern becomes less positive during the pilot, the score 4 falls to 29%, the share of score 3 is 26%, and the proportion of lower evaluations increases, with 41% of respondents selecting 2. The highest score 5, is absent. The drop in mean score reflects the weaker safety evaluations, which may be due to the limited infrastructure environment, such as a lack of continuous and protected bike lanes, interactions with motor traffic, and the fragmented nature of a few routes in the city of Monza. There is a strong need for improvement in route safety.

Speed & Convenience Comparison:

For speed and convenience, the mean score improved from 3.79 before the pilot to 4.35 during the pilot. It is connected to the findings observed in Modules 3 and 4, where cycling was perceived as faster than usual transport and where commute time slightly decreased during the pilot.

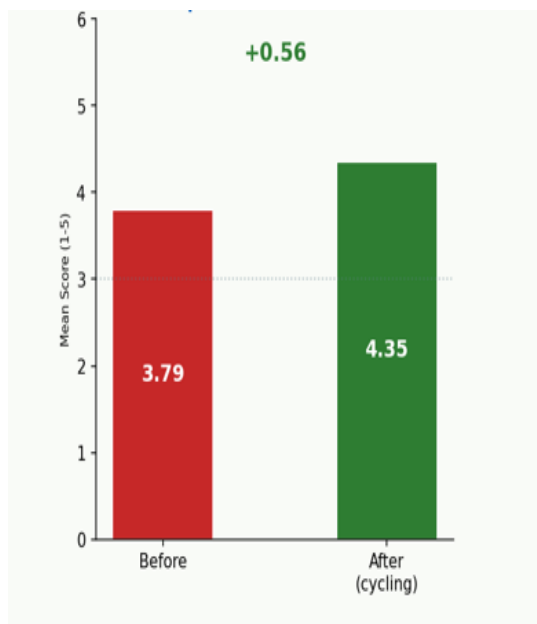


Figure 5.31: Speed & Convenience Score

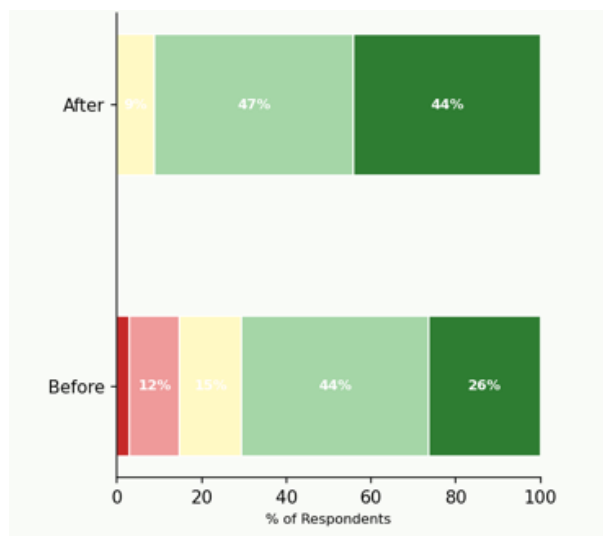


Figure 5.32: Distribution of Speed

The score distribution for speed and convenience, before the pilot, 26% of respondents give the highest score of 5, while 44% choose 4, and 15% choose 3. During the pilot, the distribution becomes more positive: the share of score 5 rises to 44%, while 47% give 4, and only 9% remain at 3. This shift shows that the users are associated with a clear strengthening of positive perceptions related to the ease of commuting by bicycle.

Change in Commuting Satisfaction:

The mean score for overall satisfaction increased from 3.76 before the pilot to 4.41 during the pilot. The increase suggests that the participants evaluated their commuting experience more positively during cycling than before, as it combined advantages such as lower cost and shorter travel time with active mobility.

The distribution of satisfaction scores explains this change in more detail. Before the pilot, 29% of respondents gave the highest score of 5, 35% giving 4, and 24% gave 3. Smaller shares are concentrated in the lower end of the scale. During the pilot, the distribution shifts clearly upward: the share of respondents giving the top score of 5 rises to 50%, while 41% give 4, and only 9% remain at 3. During the pilot, more users described their commuting experience as very positive.

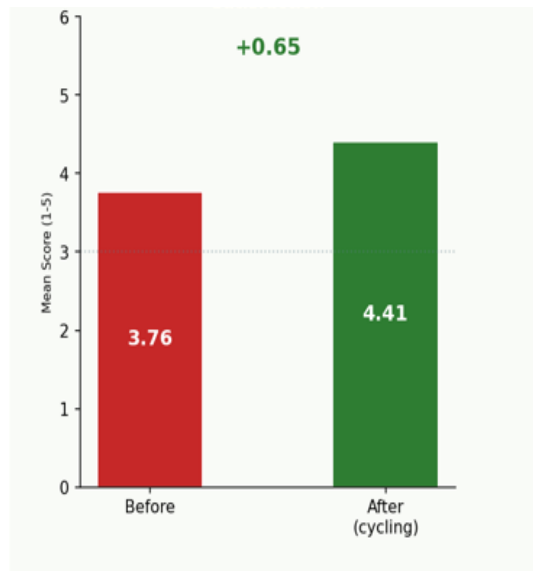


Figure 5.33: Satisfaction Score

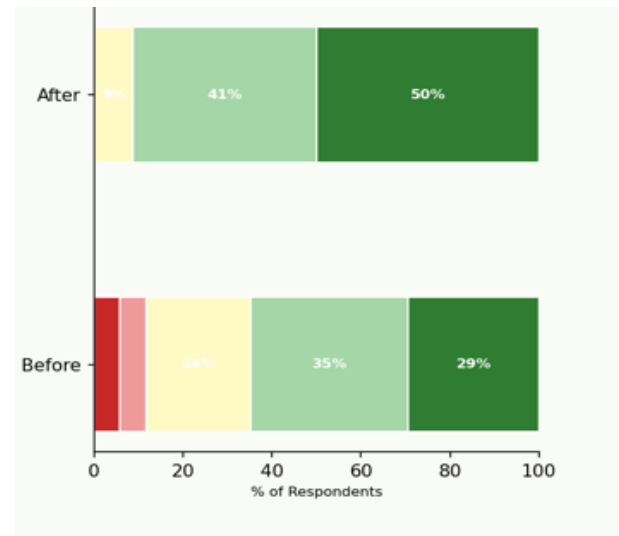


Figure 5.34: Distribution of Satisfaction

From the descriptive results, Participants perceive commuting by bike as convenient, economically beneficial, and even faster than their usual transport option; satisfaction increased, stress decreased. The participants show the potential demand for cycling in the city of Monza. The future progress depends on addressing the infrastructure-related barriers, like protected paths and secure bike parking, that continue to shape the safety and security feeling of cycling in everyday travel.

6 | Discussion

The results of the GreenPATH Monza pilot show that cycling can work as a real commuting option for many employees in Monza. From the descriptive analysis, the participants reported a more positive commuting experience in many ways. The results also show that some important problems exist, such as safety and infrastructure. Many participants felt that commuting by bike was faster, more convenient, and cheaper than their usual transport mode. Satisfaction increased during the pilot, while stress decreased. This means that the bicycle was not only accepted as a good idea in theory, but also experienced as a useful and comfortable way to travel to work or to travel in leisure time in daily life. The Gamification played an important role in this pilot. Rankings, vouchers, and rewards probably helped participants to stay involved and made the commuting experience more active and motivating. These positive experiences were not complete in every aspect. Safety remained the weakest dimension in the analysis, which makes this result important when interpreted together with the barriers identified during cycling in the other modules. The repeated mention of missing dedicated cycle lanes, fragmented routes, poor maintenance, and limited safe bicycle parking suggests that the main limits to cycling in Monza are not related to the benefits of the mode. The demand and willingness to cycle exists but the city environment is not fully ready to support cycling in a safe way. These findings suggest that improving bicycle commuting in Monza will require more than user motivation alone. In particular, safer and more continuous cycling routes, better maintenance, and more secure bicycle parking appear to be the main conditions needed to support a more stable and wider use of cycling in daily travel.

The ArcGIS-based analysis adds a spatial interpretation to the survey findings. The GPS data show two clear peaks of bicycle activity, in the morning between 7:30 and 8:30 hours, and in the evening between 16:30 and 17:30 hours, which confirms that a large part of the recorded trips are linked to regular commuting. The route-density analysis also shows that cycling demand is concentrated along a limited number of important corridors, especially in the central area of Monza and along major routes such as "Via Lecco, Via Carlo Prina, Corso Milano, Via Borgazzi and Viale Brianza".

At the same time, the comparison with the existing cycling network shows that some of these high-use corridors are only partly supported by dedicated infrastructure. The performance analysis gives a similar result, since lower cycling speeds are mainly observed in central and infrastructure-poor areas, especially around "Via Carlo Prima, Corso Milano, and Via M. Buonarroti", while smoother movement appears in more peripheral sections. The GIS results strengthen the survey findings by showing that cycling demand in Monza already exists, but the network does not yet support it fully in terms of continuity, protection, and efficiency. The origin–destination maps made the patterns much clearer. In the morning rush hours (07:30-08:30), trip origins are spread across several residential parts of Monza and outside Monza, while destinations are more concentrated around the main work-related locations in Monza. In the evening rush hours (16:30-17:30), the observed pattern is reversed: trips start more from these employment-related areas and end in a wider set of neighborhoods, which is consistent with the daily work-to-home pattern of commuting.

Recommended Cycling Infrastructure Interventions:

Based on the combined results of the survey analysis and the GIS-based analysis, Figure 6.1 summarizes the main cycling infrastructure priorities identified in this thesis, distinguishing between corridors proposed for new bicycle paths and corridors requiring redevelopment, while the legend identifies each corridor by name in the priority order.

- **Via Lecco** is the most requested route for a new bike path, and it is also mentioned second among the routes needing redevelopment in survey results. From the GIS results, it is among the corridors with more cycling demand. Therefore, Via Lecco is given first priority for interventions.
- **Via Carlo Prina** is identified as a low-speed section with absence of bike lane and it is also among the corridors with more cycling demand concentration. Via Boito is the second most requested route for a new bike path and this route appears to connect the important origin and destination areas during rush hours serving as relevant corridor for everyday commuting.
- **Via Borgazzi** is the first priority for redevelopment as per descriptive analysis due to the fragmented cycling network. **Viale Cesare Battisti** is second most favourite routes and also mentioned second for the redevelopment.

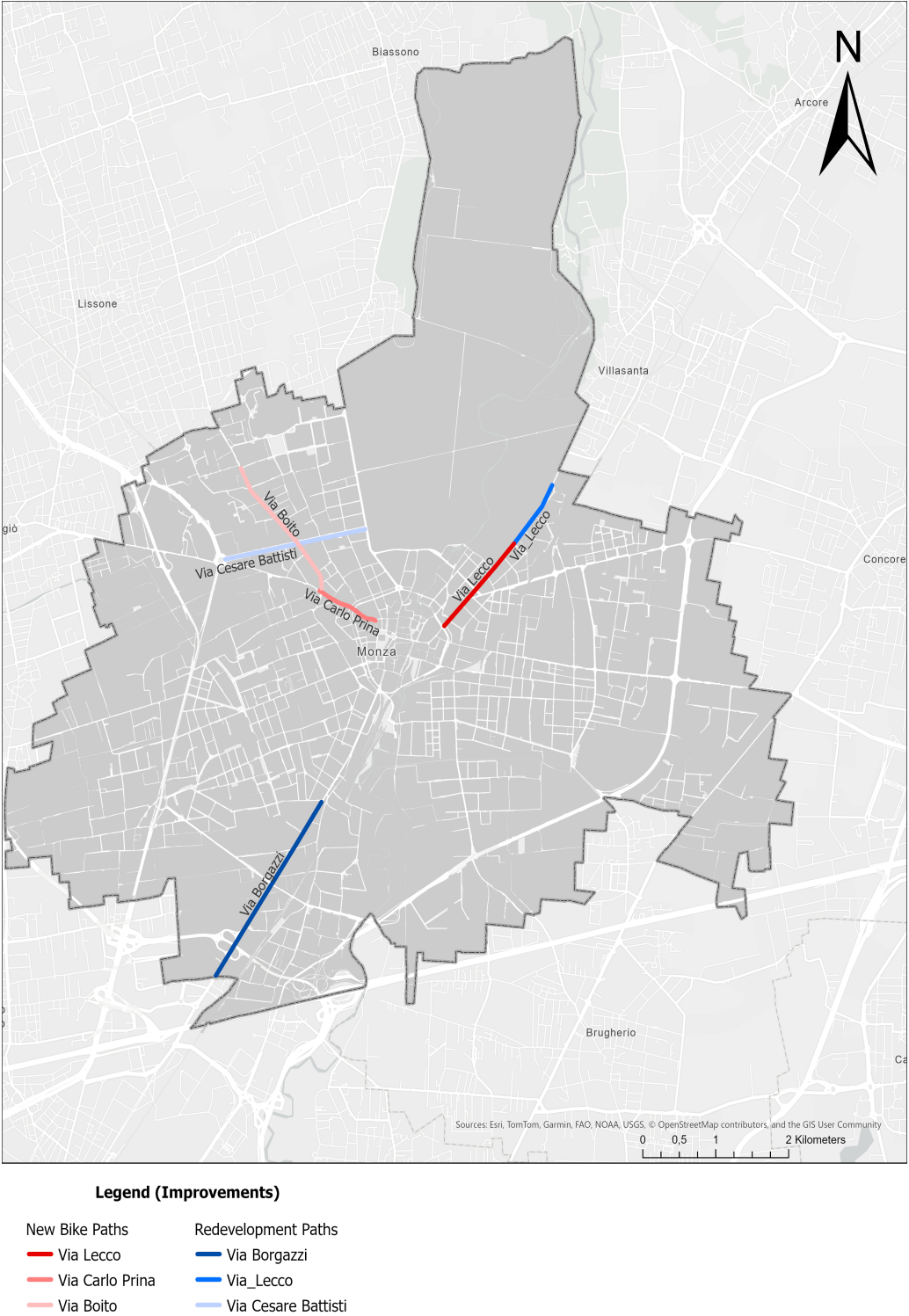


Figure 6.1: Proposed Infrastructure Interventions

Future Works

- The future work focuses on the influence of weather conditions on cycling behaviour by comparing usage across different months (e.g., August and October) and analysing the impact of rainfall and temperature variations on trip frequency, particularly during colder and rainy days.
- Another work could be how the proportion of dedicated cycling infrastructure along home-to-work routes affects users' willingness to cycle, by quantifying the percentage of cycling paths and relating it to usage patterns and perceived comfort.
- Future work also focuses on analyse of bicycle use outside the main commuting hours, including leisure trips, non-rush-hour movements, and cycling during festivals. This would make it possible to understand how bicycle use changes across different urban situations, beyond the regular home-to-work pattern.

7 | Conclusion

The findings of this thesis demonstrate that bicycle commuting can be a viable and sustainable alternative mobility in Monza. The descriptive analysis indicates that participants reported cycling as a more positive experience compared to their habitual transport mode in terms of satisfaction, convenience, stress reduction, commuting cost savings, and less travel time. The results also highlight that protected paths to workplaces are limited, cycling-related services remain insufficient, and safety is the weakest dimension. The most frequent barriers reported by participants are the lack of cycle lanes and the perception of danger, confirming that infrastructure is the key challenge. The ArcGIS-based analysis shows that cycling activity is concentrated during the 07:30 - 08:30 hours in the morning and 16:30 - 17:30 hours in the evening. Most used corridors are in the city center and on routes such as "Via Lecco, Via Carlo Prina, Corso Milano, Via Borgazzi". Critical infrastructure gaps and Lower-performance sections are visible in areas such as Via Carlo Prina, Via Buonarroti and, Corso Milano". The rush hour patterns observed in the data make it clear that most cycling activity follows daily commuting routines for travel to and from work. Cycling demand is present in Monza, but stronger route continuity, protection, and infrastructure quality are still needed to make cycling a safer, secure, and more comfortable routine for everyday mobility in the long term.

Bibliography

- [1] A. Aravind, S. Mishra, and M. Meservy. Nudging towards sustainable urban mobility: Exploring behavioral interventions for promoting public transit. URL <https://www.sciencedirect.com/science/article/pii/S1361920924000877>.
- [2] F. De Fabiis, M. Baldini, and P. Coppola. The impact of geographical context on bikeability perception: A gender-difference analysis. *Journal of Transport Geography*, 2026. URL <https://www.sciencedirect.com/science/article/pii/S0966692325004193>.
- [3] A. Lanvin, J. Charléty, G. Ferreol, A. Homann, E. Massey, A. Vermeulen, and A. Chasse. How to create a sustainable growth in bicycle traffic? the case of paris. 2025. ISSN 2950-1059. URL <https://www.sciencedirect.com/science/article/pii/S2950105925000257>.
- [4] M. Melin, A. Makkonen, S. Yrjölä, J. Peltomaa, N. Sandman, J. Tuominen, K. Vuori, M. Tainio, and P. Salo. Effectiveness of nudges for sustainable transportation: A systematic review. *Heliyon*. URL <https://www.sciencedirect.com/science/article/pii/S2405844025021577>.
- [5] Monza Mobilità. Piano urbano della mobilità sostenibile, 03 2024. URL https://monzamobilita.it/wp-content/uploads/2024/04/DocumentoPiano_28.03.24_03.pdf. Accessed: June 2026.
- [6] Pin Bike — Open Data, 2024. URL <https://web.pin.bike/open/57>.
- [7] S. Pogodzinska, M. Kiec, and C. D’Agostino. Bicycle traffic volume estimation based on gps data. *Transportation Research Procedia*, 45:874–881, 2020. URL <https://www.sciencedirect.com/science/article/pii/S2352146520301319>.
- [8] R. Thaler and C. Sunstein. *NUDGE: Improving Decisions About Health, Wealth, and Happiness*, volume 47. 06 2009. ISBN 9780141040011.
- [9] J. Weber, M. Azad, W. Riggs, and C. R. Cherry. The convergence of smartphone apps, gamification and competition to increase cycling. *Transportation Research*

- Part F: Traffic Psychology and Behaviour*, 56:333–343, 2018. URL <https://www.sciencedirect.com/science/article/pii/S1369847817306678>.
- [10] Z. Yin and D. M. Scott. Pedal preferences: Gps-based panel data insights into bike share traffic flow across membership groups. *Cities*, 170:106703, 2026. URL <https://www.sciencedirect.com/science/article/pii/S0264275125010066>.

A | Appendix A

This appendix provides supplementary material supporting the survey-based and GIS-based analyses presented in the thesis. It includes the questionnaire structure, detailed response tables, and GPS dataset information.

Survey Questionnaire used in the GreenPATH Monza pilot

Module 1 – Company HQ infrastructure and facilities. The questions referred to:

- What type of bike parking do you have available at your company premises?
- What cycling services do you have available at your company headquarters?
- Is your company headquarters accessible by a protected cycle or pedestrian path?

Module 2 – Route preferences in Monza

- If you had to choose where to build the next bike path in Monza, where would you build it? Indicate the street(s)
- If you had to choose which of Monza's existing cycle paths to redevelop, which route would you choose?
- What's your favourite bike path in Monza? Indicate the street(s)

Module 3 – Obstacles to cycling

- Which of the following factors most discourages you from cycling to work?
- What means of transport do you use when you decide not to cycle to work?
- Considering the total time from when you leave home to when you arrive at work, riding a bike rather than using your usual transportation alternative, which of the following statements is correct?

Module 4 – Travel habits before and during the pilot

- What was your transportation method before starting the GreenPATH project?

- How long did it take you to get to work before the pilot project? Considering the primary mode of transportation you selected in the previous question (one-way).
- How long does it take you to commute to work during the pilot project, when you use your bike? (One way)
- How many kilometers did you travel to and from work each day on average (round trip) before the GreenPATH project? (Regardless of the mode of transport you used)
- How many kilometers do you travel on average each day to and from work (round trip) during the GreenPATH project when you use your bike?
- How much did you spend on average each day commuting to and from work? Considering any costs for gas, parking, tickets, and passes, depending on the means of transport used (EUR)
- How much do you currently spend on average each day commuting to and from work during the project, when you use your bike? Considering any costs for trains, parking, tickets, and passes, if you use services in addition to your bike (EUR)

Module 5 – Satisfaction and feedback before and during the pilot

- How satisfied were you with the means of transportation you used for commuting before the pilot project began?
- How satisfied were you with your cycling commute during the pilot project?
- How fast and convenient do you think your commute was before the pilot project began (regardless of the means of transport used)?
- How fast and convenient do you think your bike commute is during the pilot project?
- How stressful did your commute seem to you before the pilot project began (regardless of the means of transport used)?
- How stressful do you find your bike commute during the pilot project?
- How safe did you feel when commuting before the pilot project began (regardless of the means of transport used)?
- How safe do you feel when cycling to work during the pilot project?

The questionnaire structure made it possible to analyse bicycle commuting from both a practical and experiential point of view

GIS Input Data Used for the Analysis

The input data used for the GIS-based analysis in ArcGIS Pro relied on two datasets collected during the GreenPATH Monza pilot. One dataset contains trip-level information for each recorded bicycle session, while the other contains the sequence of geographic points recorded along each trip.

The first **Trip-level bicycle session dataset** contains one record for each complete bicycle trip. It provides general information about the session, including the participant identifier, the type of bicycle used, the start and end of the trip, total duration, distance travelled, reimbursement-related values, and whether the session was classified as a home-to-work trip. This type of data is useful for understanding the characteristics of each recorded journey.

The second **Point-level GPS trajectory dataset** contains the sequence of GPS points recorded during each bicycle trip. Each record corresponds to one geographic observation taken along the route and includes the trip identifier, timestamp, latitude, longitude, and basic user-related attributes such as age range, gender, and transport mode. This dataset formed the main basis of the GIS analysis, since it allowed the reconstruction of route patterns, the identification of rush-hour movements, the mapping of cycling density, and the extraction of trip origins and destinations.

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