Università degli Studi di Milano-Bicocca

Data Science Lab on Smart Cities

Final Essay

The Impact of the New Metro Line Building

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Abstract

This study investigates the *impact of constructing new metro lines on the smartness of a city*, focusing on Milan's recent development of two advanced, automated metro lines. Key factors examined include air pollution, environmental considerations, housing costs, and demographic changes. The research aims to define and measure the evolution and modernization of Milan's neighborhoods by analyzing various variables before, during, and after the metro line's construction. Additionally, a *smartness index* will be created to compare different areas of the city. The Python code developed in the project and the interactive charts can be accessed at the following *Google Drive* link: Google Drive.

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1 Introduction to the topic

1.1 The Evolution of Urban Spaces: from Cities to Smart Cities

In the era of digitalization and accelerated urbanization, cities around the world are pursuing the goal of becoming "smart", that is, efficient, sustainable, and livable. This improvement in the quality of life of citizens is made possible thanks to the intelligent use of technologies in various sectors, including mobility, energy, security, and infrastructure. The goal is to increasingly meet the needs of people, businesses, and institutions. Around the world, different manifestations of this trend can be observed, each with its unique characteristics. London, for example, emerges in Europe as a tangible model of a city that is transforming into a "smart" entity through, among other things, the implementation of advanced mobility policies [1]. The British metropolis, in fact, has set a significant goal: by 2041, 80% of trips within the city will be made on foot, by bicycle, or by public transport. This is not a random goal, but the result of a radical transformation process that London has been experiencing for some time and that includes investments in rail transport, the optimization of road infrastructure for pedestrians and cyclists, and the redevelopment of previously degraded neighborhoods. It also involves the construction of new buildings that respect the principles of sustainability, with the ultimate goal of making London a carbon-neutral city by 2050. In addition, London, in its path to becoming a smart city, is placing a lot of emphasis on the development of green areas. An example is the "London National Park City" initiative, launched in 2019 with the aim of making 50% of the city green by 2050. Another significant project is "The Queen's Green Canopy", started in 2022, which promotes the planting of trees throughout the city, enriching parks, schools, and other public spaces. Attention to sustainability and innovation is not a phenomenon limited to London. Milan, one of the most dynamic and innovative cities in Italy, is following the same trend, evolving into a Smart City [2]. For example, it has implemented complete ultra-wide coverage, public Wi-Fi, and the 5G network, ensuring a fast and reliable connection in all areas of the city. In addition, Milan has introduced smart payment solutions, including the use of credit cards as travel tickets, contactless payments on public transport, and online ticketing for museums and monuments, making citizens' lives simpler and more convenient. From a transport perspective, Milan is innovating through the use of sensors to collect data on urban life. For example, motion sensors are used to improve traffic flow, providing real-time data that allows traffic management systems to optimize traffic light timings, reducing unnecessary stops and minimizing delays. In particular, in the subways, sensors help understand the times of greatest influx of people, allowing more efficient management of the service. In this regard, a fundamental aspect of Milan's transformation into a smart city, which will be at the center of the analysis in our report, is the construction of the new M4 and M5 subway lines built in recent years.

1.2 Advantages of Metropolitan Transport: an Analysis of the New M4 and M5 Lines in Milan

Metropolitan transport, being a fast and efficient system, improves urban mobility. This allows people to move with agility, reducing travel time, increasing productivity, and facilitating access to essential services such as work, education, and healthcare. In addition, the subway represents a sustainable solution for transport. When implemented optimally, taking into account both geographical coverage and service frequency, it can discourage the use of private vehicles. This helps to decrease traffic congestion and greenhouse gas emissions, promoting a cleaner and more sustainable environment. Finally, in recent years, new technologically advanced vehicles have been introduced, such as those using the automatic train control system, further improving the safety of the means of transport. Milan is actively working to offer numerous benefits to its citizens through the expansion of the subway network, and this commitment has materialized with the recent completion of Line M5 and the completion of Line M4. Line M5, also known as the Lilac Line, is an emblematic example of how public transport can contribute to environmental sustainability [3]. This line has led to a significant reduction in air and noise pollution, with a decrease of 15 million private car trips per year, and a reduction of about 260 road accidents per year in the city is expected. The Lilac Line, with its 12.8 kilometers and 19 stations, can transport between 15,000 and 18,000 passengers per hour per direction, offering peak frequencies of 180 seconds, which could be reduced in the future to 75 seconds. This line is also an example of how the subway can contribute to urban greenery: for every tree removed during the construction phase, three new trees were planted in the city. The commitment to environmental sustainability is also pursued in every phase of development of the new Line M4, or Blue Line, starting from the construction phase, during which non-polluting, non-toxic, and non-harmful materials were used [4]. In addition, the Municipality of Milan has committed to increasing the total number of trees by about 20% at the end of the works, through an integrated project to connect the green areas along the M4 route - Forlanini Park, Idroscalo, and Risaie Park - making them fully accessible to citizens. In general, it is estimated that the entry into operation of the new M4 and M5 lines can reduce annual car trips by about 30 million and produce a decrease in emissions of about 2%. The benefits also pass through the technology used; in fact, these mobility systems are at the forefront in terms of performance and safety, as both lines are equipped with a driverless system controlled directly by a control room that constantly ensures the correct operation of the line and the safety of passengers. The latter is also ensured through a system of dividing walls that separate the platform from the tracks and that only open when the train arrives at the station.

1.3 The Challenges of Growth: Controversial Aspects of the Subway

The expansion of the subway network in Milan is guided by the objectives of "Milan 2030", an action program for sustainable development that aims at economic growth, social inclusion, and environmental protection. Among the key objectives is the integration of peripheral areas through urbanization concentrated around transport nodes, such as subway stations. This approach aims to reduce dependence on private mobility, bringing as many people as possible closer to workplaces and living places compared to train or subway stops. However, this expansion can also be interpreted as an example of Molotch's "growth machine" in action [5]. In his essay, the author elaborates the idea that, although growth and urbanization can bring economic benefits, it is essential to recognize that they can also generate new inequalities and environmental problems. In the case of Milan, in fact, it is crucial that urban planning is careful in balancing between subway development and housing accessibility, in order to ensure integration and not lead to the exclusion of people from the community. This need arises from the fact that network expansion can lead to the so-called "subway effect", which occurs when the demand for housing near subway stations increases, causing a rise in house prices. For example, in Paris, the "Grand Paris Express" project, which aims to build over 200 km of automatic subway lines and 68 new stations by 2030, has already caused a price increase of 46% in five years in areas adjacent to four stations inaugurated between December 2020 and January 2021 [6]. Milan is experiencing this phenomenon, made evident by the construction of the new M4 line. In this regard, an analysis conducted by Immobiliare.it in July 2023 [7] examined the evolution of the prices of three-room apartments in areas adjacent to the new M4 stops, in the period between 2016 and 2022. The study found that, starting from 2016, there was a significant increase in housing prices: in the Susa area, for example, the increase was 55 while in Forlanini it was 40Å more detailed analysis considered the prices of three-room apartments in the Tricolore district, comparing them with those of an area of Milan not served by the subway. This comparison highlighted that, until the beginning of 2022, prices grew homogeneously, with an increase of 33% since 2016. However, with the opening of the subway, the Tricolore district recorded an increase in the prices of three-room apartments of 46%, exceeding the increase of 40% found in the other district. This phenomenon, experienced in numerous cities around the world, can trigger a process of gentrification [8]. In practice, due to the increase in house prices, residents with lower incomes may be forced to move to more peripheral areas, where housing is cheaper but the convenience of the subway is not available. This entails several disadvantages, among which it can lead to a greater need for the car for travel, thus contradicting the objective of reducing dependence on private mobility. In addition, gentrification can have a significant impact on ethnic minorities, particularly those who have immigrated, who may already be in a disadvantaged position due to linguistic, cultural, and socioeconomic barriers and due to this phenomenon may have further difficulties in maintaining or improving their social position. Often, it is precisely this part of the inhabitants who leave the gentrified neighborhoods, causing a demographic transformation that leads to a loss of cultural diversity and the formation of ethnic enclaves in the outskirts of cities.

1.4 Objectives of the Project

Our analysis focuses on the evolution of some key variables in the neighborhoods of Milan, in particular: green areas, air quality, property prices, and population diversity. We will examine the impact of the project of a new subway line, observing how these variables change during the phases of approval, construction, and opening of the new stations. This detailed study will allow us to understand how each phase of the infrastructure project has influenced various aspects of urban life and the composition of the neighborhoods. To achieve this goal, we have developed a smartness index that allows attributing a development score to each variable considered individually and to the aggregate variables. The smartness index will be observed annually for the neighborhoods of Milan and for the city as a whole, allowing us to have a complete view of the temporal development of smartness. Thanks to this methodology, we will be able to determine whether the neighborhoods crossed by the new subway line have recorded greater development, in terms of smartness, compared to those not served by the subway and whether this development has been positive or negative.

2 Smartness

In this chapter, the various variables considered in the subsequent analyses will be defined, along with the creation of a custom index related to smartness, which refers to the level of development and modernization of a specific area.

2.1 The concept of smart city

Before delving into the variables considered for our case study, it is necessary to define the concept of a *smart city*, measured in terms of several fundamental dimensions. Over the years, various scholars have contributed to outlining different sets of relevant factors. One of the most widely regarded definitions is that proposed by *Lombardi* [9], which considers the following variables to define a smart city:

- **Intelligence**: refers to a city's ability to use advanced technologies and data to enhance governance and urban planning, proactively addressing the needs of its citizens. This can occur, for example, through the creation of an intelligent transportation system, smart energy grids, and air quality monitoring;
- **Sustainability**: refers to the promotion of eco-friendly practices to reduce environmental impact. This aspect involves crucial activities such as sustainable water resource management and the promotion of sustainable mobility through the use of green public transportation and bike lanes;
- **Comfort**: concerns the enhancement of citizens' well-being and quality of life through efficient services and welcoming urban environments. This includes the design of green spaces and parks, safe infrastructure, and affordable housing;
- **Quality of life**: refers to the overall well-being and satisfaction of residents. It encompasses aspects such as access to education, culture, healthcare, safety, and social participation;
- **Urbanization**: concerns the management of urban growth, focusing on the sustainable planning and development of urban infrastructure and the integration of peripheral areas. This includes, for example, efficient traffic management and the development of residential zones integrated with public services.

These dimensional macro-areas defined by *Lombardi* serve as the foundation for conducting specific analyses by considering sub-variables for each of them. The goal is to measure a city's smartness in numerical terms, using multiple data sources and integrating the different dimensions.

2.2 Defining our smartness: the variables

For our research, we consider several factors related to smartness, consistent with the definition provided by *Lombardi*. Here is the list of variables studied, with reference to the city of Milan and the objectives of our project:

- **Environmental Variable - Urban Greenery**

  The first factor under consideration pertains to the quantity, distribution, and quality of urban green spaces, such as parks, public gardens, and wooded areas. Enhancing and preserving green spaces contributes to better air quality, improved public health, and greater biodiversity, consequently enhancing the quality of life for residents.

  Through our analysis, we aim to evaluate the evolution of urban greenery before and after the construction of new subway lines, studying environmental development in the city of Milan, with particular reference to areas affected by the new metro line stops. In accordance with Lombardi's definition, the associated dimensions are *sustainability, comfort, and urbanization*;

- **Air Quality Variable - Atmospheric Pollutants**

  Another fundamental aspect to consider when assessing smartness is the concentration of pollutants present in the atmosphere. Improving air quality is a key objective for smart cities, as it directly affects public health and environmental sustainability. Initiatives in this regard often prioritize reducing emissions and monitoring air quality using advanced technologies.

In detail, we consider these pollutants along with their associated safety limits:

– PM10 particulate matter [10];
– PM2.5 particulate matter [11];
– Carbon monoxide (CO) [12].

Air quality is influenced by factors such as vehicle emissions, industrial activities, and sustainable mobility policies. In our study, it is interesting to understand how and if the introduction of new subway lines has effectively reduced atmospheric pollution in the city of Milan. In reference to Lombardi's definition, the associated dimensions are *intelligence and quality of life*;

- **Air Quality Variable - Vehicles and EURO Categories**

  This variable refers to the set of vehicles (cars and motorcycles) registered in a specific geographic area in terms of the *EURO emission class* related to atmospheric pollutant emissions [13]. Encouraging the purchase of more eco-friendly vehicles and the use of public transportation (resulting in a reduction in the number of vehicles in circulation) are key aspects of smart city projects.

  For our project, the goal is to obtain an aggregated variable that considers the concentration of atmospheric pollutants and the percentages of vehicles for the EURO standard, to understand if the introduction of a new metro line is a factor in improving air quality. In reference to Lombardi's definition, the associated dimension is *sustainability*;

- **Economic Variable - Property Prices**

  In the economic domain, we have considered the purchase price per square meter of residential properties, analyzing it, for example, in specific areas of the Municipality of Milan. The *Osservatorio del Mercato Immobiliare (Agenzia delle Entrate)* [14] divides territories into *Zone OMI* [15] and records the purchase price of properties for each zone semi-annually [16], providing multiple analyzable data points.

  While higher property prices can indicate improved infrastructure and desirability, they can also lead to issues related to affordability and social equity. Monitoring property prices helps in assessing economic growth and planning affordable housing solutions.

  Among the various factors influencing housing costs, proximity to public transportation infrastructure, such as subway lines, is one of the most significant, an aspect we will consider for the Milan subway system in the subsequent chapter regarding analyses. In reference to Lombardi's definition, the associated dimension is *comfort*;

- **Social variable - Population diversity**

  The last factor considered relates to the demographic composition of residents in a specific area, in terms of citizenship and the percentages of Italians and foreigners. This aspect is particularly relevant for studying population diversity within the Municipality of Milan, analyzing the evolution over time of various ethnicities in areas undergoing substantial urban development and therefore experiencing increased housing costs.

  A diverse population indicates social inclusivity and cultural richness, which are important for the vibrancy and resilience of a city. Smart city initiatives often aim to foster inclusivity and equitable access to services for all residents. In reference to Lombardi's definition, the associated dimensions are comfort and quality of life.

For each of the variables just described, an associated *sub-index* will be created within the range [0,1], quantifying numerically the development in the specific sector of reference (further details will be provided in the chapter concerning the methodologies).

2.3 The Smartness Index

As previously mentioned, the key final objective is to construct a smartness index that combines the various variables just described into a single representative number, reflecting development across different sectors of a specific area. By doing so, we aim to quantify smartness in easily interpretable and comparable terms, both spatially and temporally. The methodology that will be introduced shortly not only allows for the aforementioned comparison but also offers the possibility of changing the granularity of analysis to compare different cities and areas (considering the same set of starting variables).

In the methodologies chapter, the functioning of the index will be examined in detail. For now, it is sufficient to know that the smartness index is:

- a number within the range [0,1], where a higher value indicates greater smartness for the area;
- a linear combination of the sub-indices related to the previously described variables, where each factor has the same weight in defining the smartness of a specific territory.

In conclusion, this chapter has defined the concepts of a *smart city*, the considered *variables*, and the *smartness index*, laying the foundation for the subsequent discussions on the methodologies used and the studies conducted.

3 Methodologies, Variables and Index Construction

This chapter focuses on the general definition of the methodologies utilized within the project and the construction of sub-indices for variables and the smartness index.

3.1 Milan's neighborhoods and metro lines

At the heart of this project lies the division of the Municipality of Milan into neighborhoods, a critical level of granularity chosen for subsequent examinations. In 2019, the Municipality of Milan ratified the *Piano di Governo del Territorio (PGT Milano 2030)* [17], which segmented the municipal area into *88 neighborhoods*, termed *Nuclei d'Identità Locale (NIL)* [18]. *Figure 1* showcases the different regions (neighborhoods) along with their unique identifiers, which will be employed in the project's analyses.

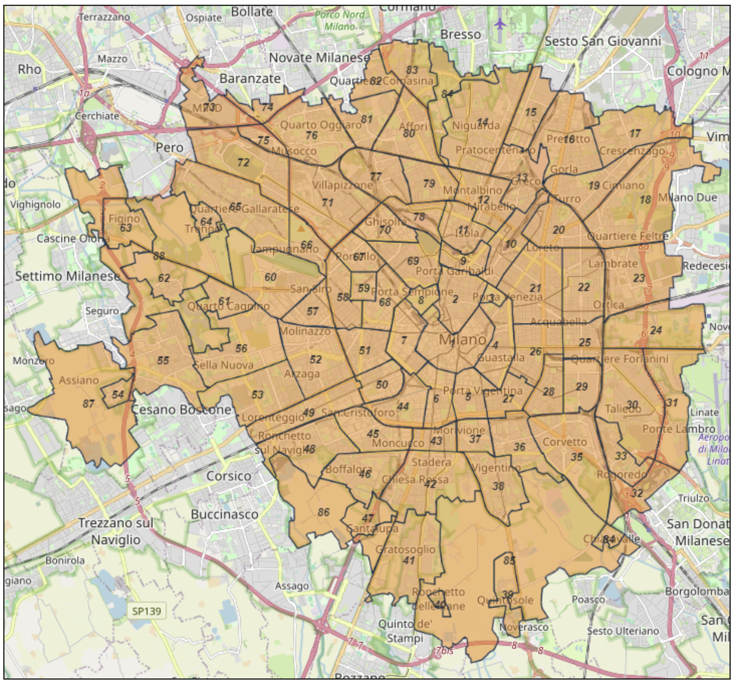

Figure 1: Map of Milan's neighborhoods

As already extensively outlined, the central aspect of this project is the *metro lines*, with a particular focus on the areas impacted by the construction and opening of the M5 line and the brand-new M4 line, which is still under development. We will now delve into identifying the neighborhoods that will be the focal points in terms of smartness evolution, understanding some basic aspects and characteristics for subsequent analyses.

- **Metro line M5**

  The project for the construction of the M5 metro line [19] was approved in the final months of 2006, marking the starting point of our analyses. Construction began in mid-2007, with the first stations opening in 2013. The entire line became operational in 2015. Thus, the analysis period for the M5 spans a decade, from 2006 to 2016. This transportation innovation affects 15 neighborhoods, primarily in the northern and northwestern parts of the city. To determine which neighborhoods to focus on, it is useful to analyze them in terms of pre-existing public services and their geographical location:

  - **Previously Served Neighborhoods**: the Bicocca neighborhood (15) is distinguished by the presence of the Milano-Greco Pirelli train station. The Porta Garibaldi-Porta Nuova neighborhood (9) has always been a hub, featuring the Garibaldi FS station with connections to trains and the M2 metro line. The Pagano neighborhood (68) also had connections to both the metro (M1) and the Milano-Domodossola train station. Lastly, neighborhoods 58 and 66 have metro stops on the M1 line (Lotto, Segesta, QT8, and De Angeli);
  - **Potentially Most Impacted Neighborhoods**: the regions that may have experienced the most significant impact from the new metro stops are primarily neighborhoods 60 and 57, namely the San Siro area, which includes the stadium and the racetrack. The Tre Torri neighborhood (59), which has been completely renovated, has become a bustling center of life and business in the city. Additionally, the neighborhoods of Isola (11), Niguarda (14), Maggiolina (12), Portello (67), and Sarpi (69) should also be considered.

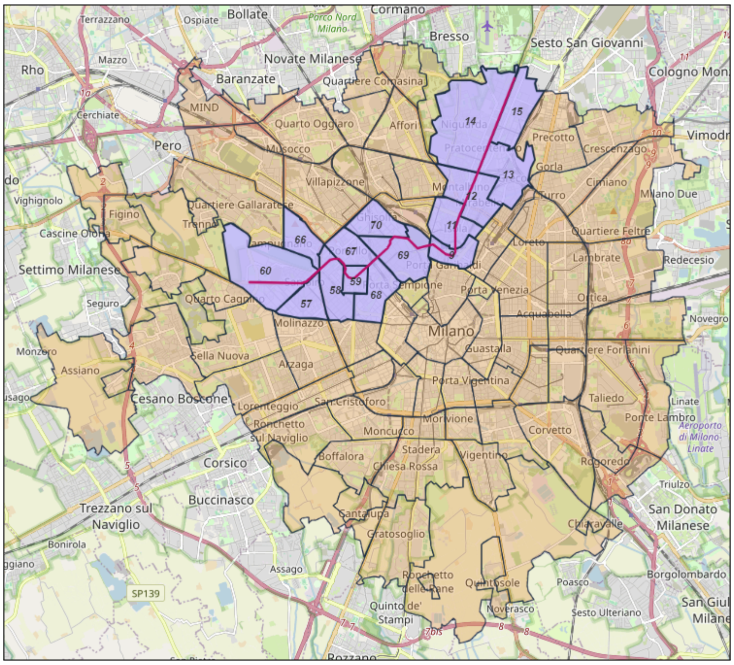

Figure 2: Map of metro line M5

- **Metro line M4**

  The latest metro line in the Municipality of Milan, still under construction, is the M4 [20], much of which is not yet accessible to the public. The project was approved in 2011, and construction began in 2012. The first segment opened between late 2022 and 2023, running from Milan-Linate Airport to San Babila (from the east-central part to the city center). In this regard, the neighborhoods to be particularly considered in subsequent analyses are Forlanini (24 and 30), Corsica (25), XXII Marzo (26), and Guastalla (4). For future openings, the entire western area is expected to see significant development in various aspects related to modernization, construction, and improvements (look at *Figure 3*).

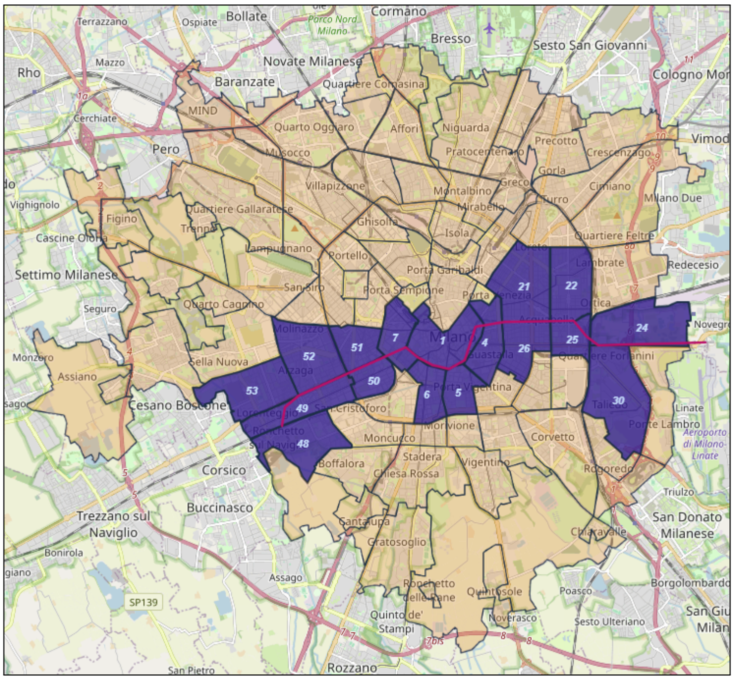

Figure 3: Map of metro line M4

3.2 Variables and Index

As outlined in the previous chapter, this study examines multiple factors, each necessitating the creation of a distinct index that consolidates various sub-variables relevant to the context. Specifically, the elements for which indices will be formulated include: environment, air quality, real estate market, and population diversity.

The constructed indices will range from 0 to 1, where values approaching 1 indicate better development in the given area under consideration.

This section delineates the methodologies utilized to construct indices for the aforementioned factors. It encompasses a detailed explanation of the components assessed and the implications of the resulting values, offering a comprehensive overview before advancing to the analytical segment.

- **Environmental Variable - Green Area Index**

  The first variable considered is related to the environment, with the objective of obtaining an environmental development index for urban greenery in each neighborhood by aggregating a series of components.

  In detail, for each NIL area, the following were considered:

  - the number of trees [21];
  - the area allocated to urban gardens (in square meters) [22];
  - the area designated for urban animal parks (in square meters) [23];

  To calculate the urban greenery development index for each neighborhood and year, we followed these steps:

  1. Summation of the areas allocated to urban gardens and animal parks to obtain a total urban greenery area. Subsequently, the urban greenery index (UGI) was calculated using min-max normalization, where a value close to 1 indicates high environmental development;
  2. Calculation of the tree index (TI), also using min-max normalization, where a value close to 1 indicates better environmental development;
  3. Computation of the final environmental development index, called the green area index (GAI), by aggregating the two previously described indices with different weights. Specifically:

$$\text{GAI} = \text{UGI} \times 0.3 + \text{TI} \times 0.7 \tag{1}$$

Thus, the final index will have a value between 0 and 1, where a value close to 1 will be associated with neighborhoods with higher environmental development.

- **Air Quality Variable - Air Quality Index**

  The second aspect studied is related to atmospheric pollution (considered at the municipal level rather than the individual neighborhood), focusing on two fundamental variables in this context:

  - air quality, measured through the analysis of the concentrations of previously mentioned pollutants [24];
  - percentages of vehicles with European emission standards [25].

  The computation of the index followed these steps:

  1. Each pollutant was divided by the associated safety limit to account for the exceedance of regulatory thresholds, and a min-max normalization was performed at the level of individual pollutants, obtaining values in the range [0,1] where higher values indicate greater exceedance of the maximum limit;
  2. Calculation of the air pollution index (API), by aggregating the normalized values of pollutants for each year, maintaining equal weight for all. This sub-index will have a value close to 1 when the air is more polluted;
  3. For the EUR class vehicles, the ratio of vehicles in each class to the total number of vehicles was calculated. Subsequently, the EUR Class Index (ECI) was computed as follows:

     $$\mathrm{ECI} = \mathrm{ratio}_{\mathrm{EUR6}} \times 0.6 + \mathrm{ratio}_{\mathrm{EUR5}} \times 0.25 + \mathrm{ratio}_{\mathrm{EUR4}} \times 0.15 \quad (2)$$

     This approach assigns greater weight to years with more EUR6 vehicles and, to a lesser extent, EUR5 and EUR4 categories. A value close to 1 indicates a higher percentage of vehicles emitting fewer pollutants, thus better air quality;
  4. Finally, the index related to air quality, called the Air Quality Index (AQI), was constructed by aggregating the previously created indices related to air pollution and vehicles with European emission standards with equal weight:

     $$\mathrm{AQI} = ((1 - \mathrm{API}) + \mathrm{ECI}) \times 0.5 \quad (3)$$

     Note that the Air Pollution Index was inverted before calculating the final index because the objective is to obtain an air quality index that penalizes pollution, resulting in a value close to 1 if the air quality is among the best in the considered period.

- **Economic Variable - Real Estate Market Index**

  Regarding the economic variable, we considered the value of real estate prices per square meter from the OMI real estate quotes data [26]. The Real Estate Market Index takes into account two factors: the market value of privately used homes and the year-on-year growth rate. The goal is to construct an index with a value between 0 and 1, where 1 signifies low real estate prices and a low year-on-year increase in value.

  To achieve our objective:

  1. Firstly, we needed to perform an operation using the geospatial data of the OMI Zones and the neighborhoods of Milan, in order to establish a correspondence between these areas;
  2. We calculated the year-on-year increase within the same neighborhood, and then normalized it globally using min-max normalization, obtaining a sub-index related to the growth rate (Growth Rate Index, GRI), where 1 represents the highest year-on-year increase;
  3. We normalized the market value of homes using min-max normalization, obtaining the Market Value Index (MVI) sub-index;
  4. The final Real Estate Market Index (REMI) is computed as follows:

     $$\mathrm{REMI} = (1 - \mathrm{GRI}) \times 0.6 + (1 - \mathrm{MVI}) \times 0.4 \quad (4)$$

     This approach results in an index ranging from 0 to 1, consistent with the previously outlined criteria (thanks to the inversion of the sub-indices).

- **Social Variable - Diversity Index**

  The last variable considered is the social one, for which the Diversity Index has been constructed. This index represents the diversity of the population in terms of citizenships and foreigners, with data obtained from the Open Data of the Municipality of Milan [27]. In detail:

  1. For each neighborhood and year, the ratio of foreigners to total residents and the number of different citizenships were computed;
  2. Two scores were calculated using min-max normalization, resulting in a score between 0 and 1, where 1 represents respectively the highest ratio of foreigners and the highest number of citizenships in neighborhoods per year;
  3. The final diversity index was computed by weighting the citizenship score by 0.7 and the foreigner ratio score by 0.3.

- **The Smartness Index**

  The final Smartness Index has been calculated by aggregating the previously defined indices, namely the Green Area Index, Air Quality Index, Real Estate Market Index, and Diversity Index:

$$\text{Smartness Index} = (GAI + AQI + REMI + DI) \times 0.25 \tag{5}$$

  This index is in the range [0,1], where 1 represents the highest level of smartness for the neighborhood.

With this section concluded, all the components necessary to better understand the analyses have been delineated and thoroughly explored. In the next chapter, multiple phenomena concerning the impact of subways in the city of Milan will be studied using the indices just described.

4 Data Analysis

4.1 Analysis 1: an Overview of the Indices around Milan

In the following chart, we can observe the evolution of the smartness index and each variable that composes the smartness in Milan from 2006 to 2023. Furthermore, the openings of the M5 line, fully operational since November 2015, and the M4 line, whose first section was opened in November 2022, are highlighted.

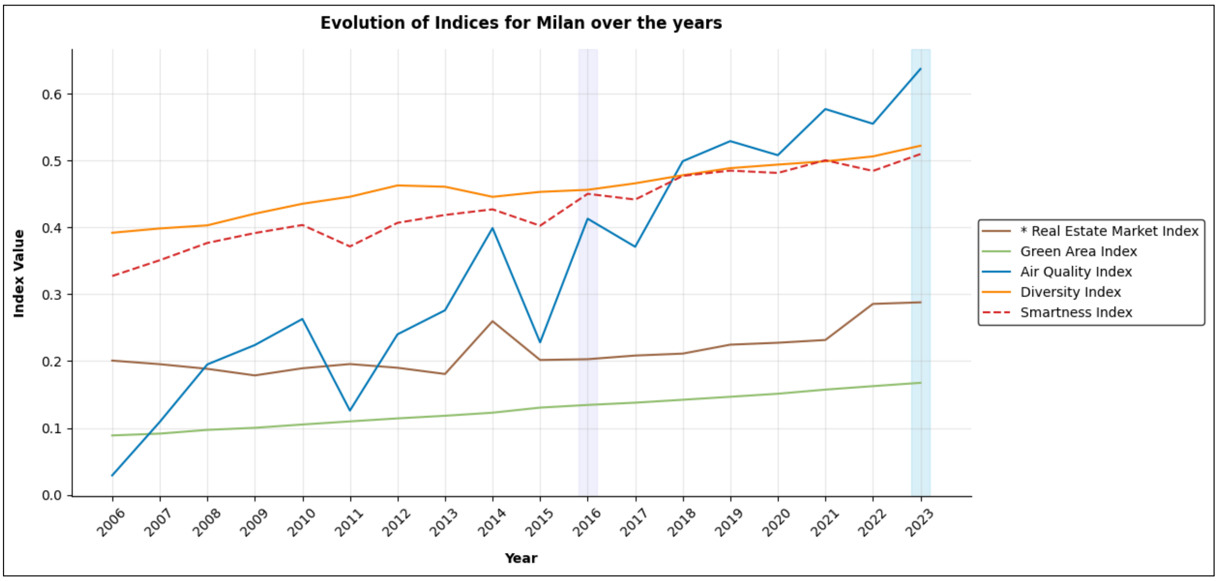

Figure 4: an overview of the indices around Milan

Observing the figure, it is evident that all variables show an increasing trend in the analyzed period. Particularly, it can be noticed that after the complete opening of the M5 line, the trend of all variables has shown a more consistent and less fluctuating growth. This is particularly evident in the case of the Air Quality Index, which presents an overall exponential trend, despite recording significant declines in 2011 and 2013. These declines can be attributed to numerous factors not clearly identifiable through our analysis. However, what clearly emerges is that from the beginning of 2016, with the full operation of the new subway line, the positive trend seems to have become more stable compared to previous years. This could also be influenced by the increasing trend of the Green Area Index, which shows a slower but steady growth, confirming that the construction of new subway lines, in line with the commitment made by the Municipality of Milan, also leads to an increase in green areas in the city and greater use of public transport, reducing private travel. The Diversity Index also seems to have a rather slow but steady growth, despite a decline in 2013. It is interesting to observe how this decline corresponds, in the same period, to a considerable increase in property prices. Regarding the real estate market index, a clarification is necessary: as previously mentioned, it reaches higher levels when the price of properties decreases, indicating an improvement in the smartness index. However, in all the charts presented in this chapter, its complement is represented. This is done to show an increasing trend for price increases and a decreasing trend for reductions, in order to make the analysis as clear as possible. In general, the Smartness Index presents a constant and significant growth, highlighting how technological innovation and smart infrastructures are becoming increasingly prominent in the neighborhoods of Milan.

4.2 Analysis 2: Average Evolution of Indices in Neighborhoods with and without Metro

Here, we examine the evolution of the indices of interest in neighborhoods with and without subway service. Among the four factors that make up the overall Smartness Index, the Air Quality Index is calculated for Milan as a whole; therefore, since it would present an identical trend in both charts, it is not represented below.

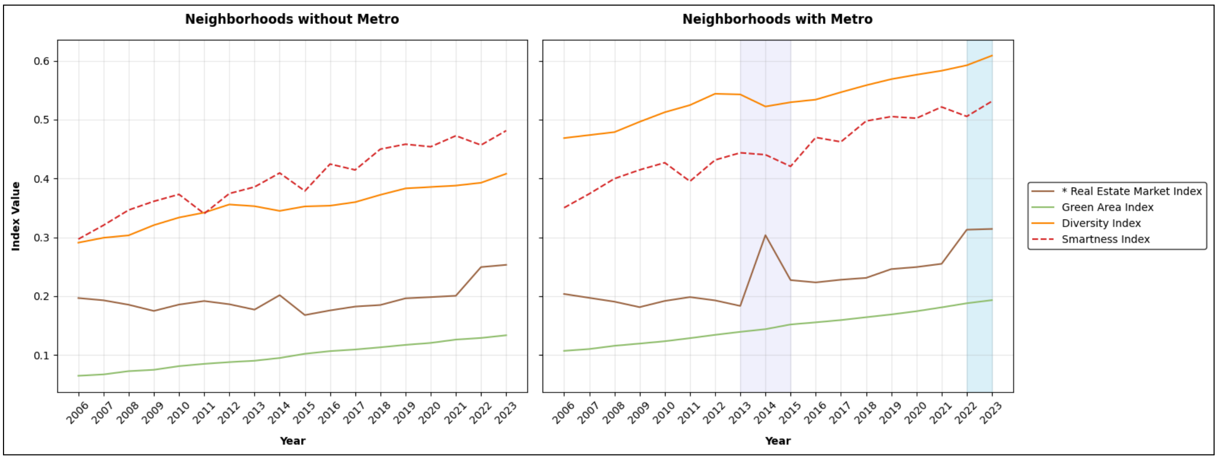

Figure 5: average evolution of indices in neighborhoods with and without metro

This more focused view on neighborhoods with and without subways allows us to understand the causes of what was analyzed in the previous chart. In general, it can be observed that in neighborhoods equipped with subway service, the index values are higher and the smartness index reaches higher levels in 2023. However, a more careful observation of the trend of the variables analyzed in these areas of Milan leads us to make interesting considerations, which do not lead, as one might think, to affirm that neighborhoods with the subway are absolutely better, in terms of smartness, compared to those without a subway. What is most interesting to observe within these charts is the behavior of the indices in the pre-operational and operational phases of the M5 line. Indeed, in these years the peak in property prices and the decline of the diversity index are glaring. By definition, the smartness index is positively influenced by greater diversity in the population and negatively when property prices increase. For this reason, it is not surprising that in the years when there was the prospect of the imminent operation of the M5, house prices increased, leading to a decline in the smartness index. This negative trend was also influenced by a lowering of the diversity index. Although aware that the complexity of the migration phenomenon cannot be fully explained with the variables we have, the observation of the chart leads us to consider the possible implementation of the gentrification phenomenon described at the opening of this report.

4.3 Analysis 3: Comparison between Neighborhoods with M5 and the other Neighborhoods

In the following chart, we aim to highlight the significant trend change of the indices during the activation period of the M5 line in the neighborhoods it crosses. To do this, we followed several steps. Firstly, we calculated the average annual percentage increase compared to 2006 for the neighborhoods crossed by the M5 and for the other neighborhoods. Subsequently, we calculated the difference between these two increases and analyzed it in the chart.

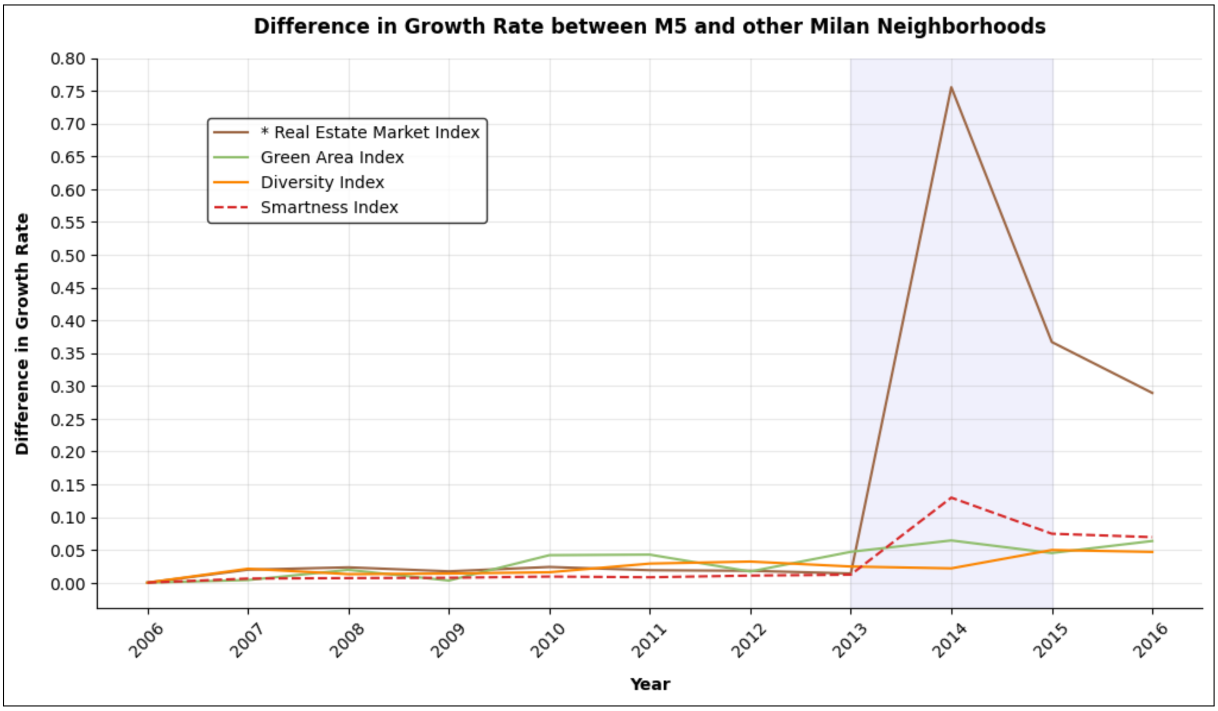

Figure 6: comparison between neighborhoods with M5 and the other neighborhoods

It is important to note that, before 2013, there was not a significant difference between the two areas in the increase of variables compared to 2006. However, with the start of operation of the new subway, it's evident that the difference in the growth rate becomes significantly more pronounced, particularly for the Real Estate Market Index. This demonstrates that the introduction of a new subway line indeed has an impact on all the variables we consider in the neighborhoods it crosses. In the following chart, we will better illustrate this trend by observing specific neighborhoods for the two areas considered.

4.4 Focus: Growth Rate Comparison, M5-Crossed vs. Other Milan Neighborhoods

In the following section, we will specifically examine the factors that contribute to the difference in the increases previously analyzed. In particular, we will consider the average growth rate of the variables from 2013 to 2016 for some representative neighborhoods served by the M5 and for others not served by this new line.

Although the trends are similar, it's important to note that the increase in the smartness index is lower for neighborhoods crossed by the M5, due to the rise in property prices and the decrease in the diversity index. However, it's important to emphasize that this does not imply that the introduction of a subway line has a negative impact on the smartness index. Rather, due to various factors, the development of the smartness index might be slower initially. In fact, as highlighted in the second chart of our analysis, at the end of the study period, despite some variables slowing down the progress of smartness, neighborhoods with the subway have still proven to be smarter than those without this service.

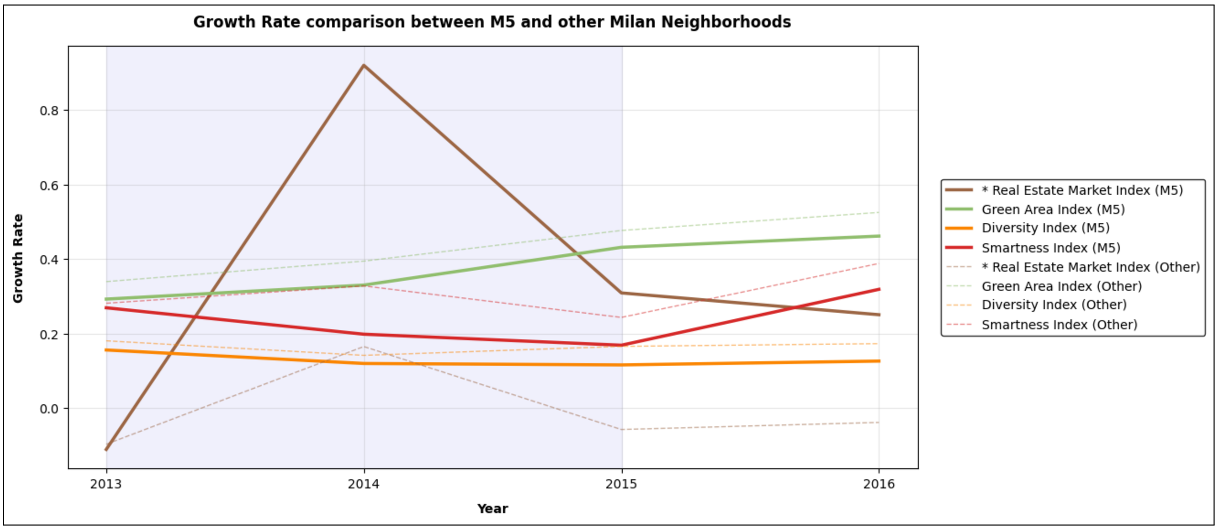

Figure 7: growth rate comparison, M5-Crossed vs. other Milan neighborhoods

4.5 Analysis 4: Growth Comparison, Metro-Introduced vs. Unchanged Neighborhoods Post-2016

In the following example, we see a case where the introduction of the subway has had a significant impact on the neighborhood it crosses. Here, we observe two groups of neighborhoods that start from the same initial condition in terms of availability of public services: in fact, both groups, before 2013, did not have a metropolitan or railway transport service. However, starting from 2013, the neighborhoods represented in the left chart began to benefit from the M5 service, while the neighborhoods represented in the right chart continued to have limited public transport service.

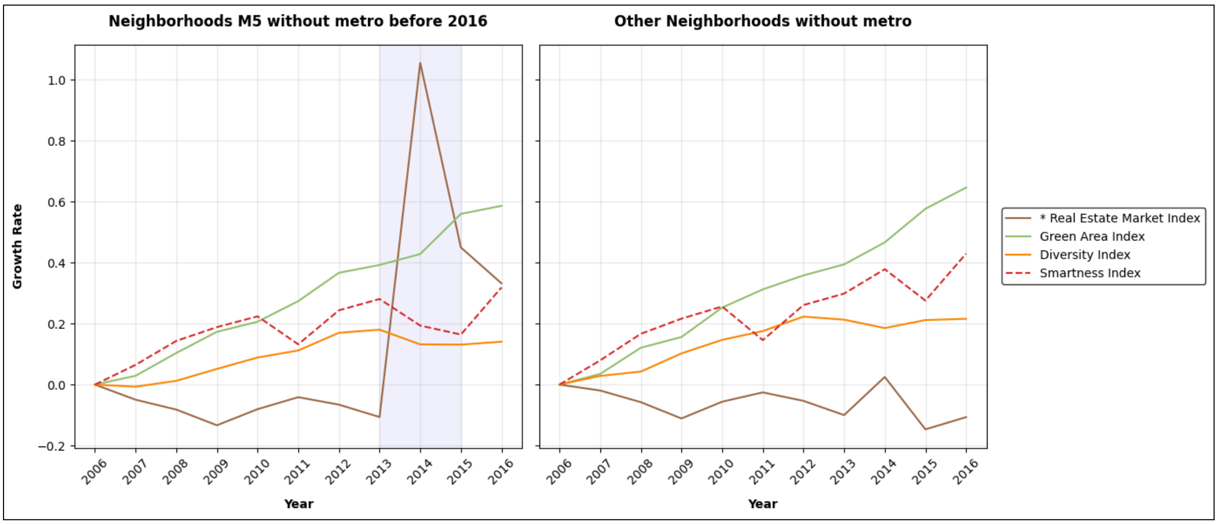

Figure 8: growth comparison, metro-Introduced vs. unchanged neighborhoods post-2016

These charts, which present identical starting situations for the considered neighborhoods, confirm what was stated earlier. They demonstrate that the more pronounced negative trend of the smartness index for neighborhoods served by the M5 is caused by the significant increase in property prices. This increase did not affect the smartness index of the neighborhoods not served by the mentioned transports in the same way, as the real estate market remained more stable. At the same time, it is noted that the diversity in the population decreases more for the neighborhoods that will be served by the M5 line, which once again demonstrates the phenomenon of gentrification mentioned earlier.

4.6 Analysis 5: Growth Rate of each variable for M5 Neighborhoods and other Milan Neighborhoods

This analysis focuses on comparing the average growth rate from 2006 to 2016 of the neighborhoods served by the M5 line and those in the rest of the Municipality of Milan.

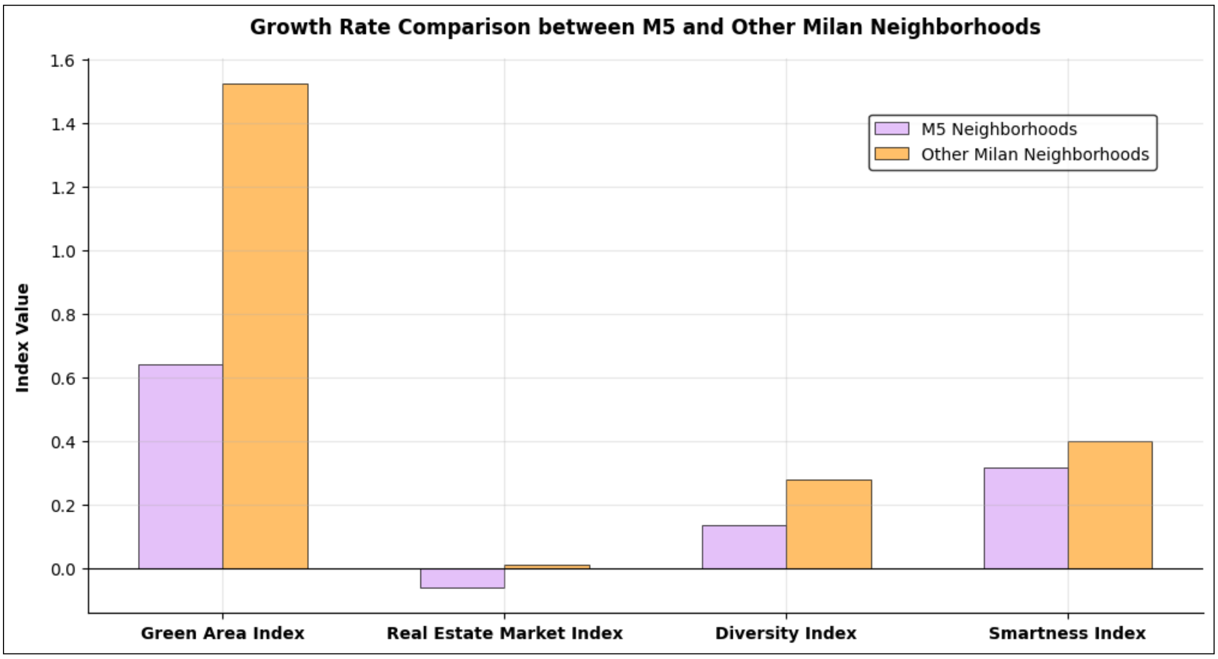

Figure 9: growth Rate of each variable for M5 neighborhoods and other Milan neighborhoods

The bar chart in *Figure 9* considers various indices under examination, revealing some interesting differences to highlight:

- in terms of the Green Area Index, the disparity is clear; in neighborhoods not affected by the construction of the new subway, on average, the growth rate is more than double, suggesting that urbanization due to the construction of the new M5 subway line has not kept pace in terms of green areas. At the same time, this aspect is influenced by the significant growth in terms of green areas in the more peripheral neighborhoods of the Municipality of Milan;
- the Real Estate Market Index remains almost the same in other neighborhoods of Milan, while in those related to the M5 line, there is a decrease, which signifies a significant increase in property prices;
- confirming the phenomenon of gentrification, we see how on average the diversity index has grown half as much in the M5 neighborhoods compared to the rest of Milan;
- finally, in terms of the smartness index, the difference is less pronounced, but still present: neighborhoods not affected by the new subway line grow slightly better than the others, as already noted and explained in detail in previous analyses.

4.7 Focus: Neighborhoods with the highest M5 Growth Rate

We aim to briefly analyze which neighborhoods are indeed most positively influenced by the presence of the new M5 subway line. To do this, we consider the percentage increase in the smartness index from 2006 to 2016 (the decade of analysis of the M5 line), to understand which areas have experienced the greatest growth in overall development. The following table shows the top three neighborhoods by percentage increase.

Neighborhood Name	Percentage Increase
Niguarda	45.73%
Bicocca	43.89%
Greco	41%

Table 1: Percentage Increase of the Smartness Index

Considering that the average increase for the entire municipality of Milan is about 38%, we see how the neighborhoods of Niguarda, Bicocca, and Greco have had an increase in smartness of 2%, 4%, and 8% respectively compared to the average. The rest of the neighborhoods, on the other hand, remain below the municipal average. This is in line with the phenomena and explanations outlined earlier, especially in terms of the growth in smartness a few years later in the neighborhoods served by the M5

4.8 Analysis 6: Comparison between M4 and M5 Metro Lines

This in-depth analysis compares the evolution of the growth rate of the indices within the neighborhoods of the M5 and M4 lines. For both lines, the starting year is represented by the year of project approval, and the growth rate is computed year by year, allowing for a comparison of trends.

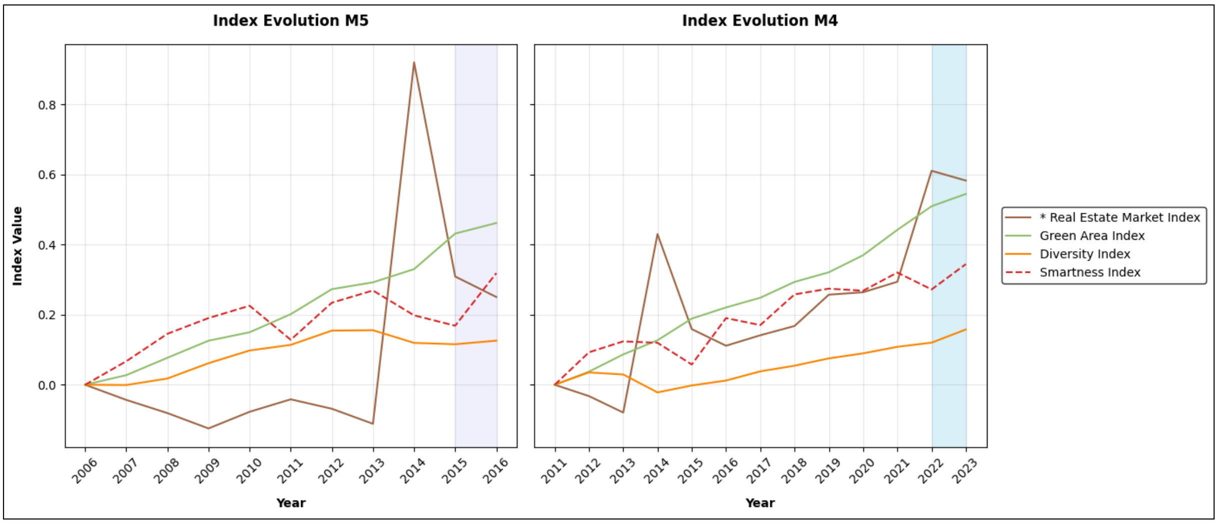

Figure 10: comparison between M4 and M5 subway lines

Observing the two charts, we can notice two interesting phenomena:

- the evolution of the smartness index trend is very similar, which is particularly relevant for our analysis: considering the growth rate for the two subways, built in different periods, a common pattern emerges tending to increase the smartness by about 35% from the approval of the project to the operation of the line. Furthermore, we also notice how during the construction phase there are very similar fluctuations, confirming the patterns found in the growth path of the neighborhoods where a new subway line is built;
- the periods highlighted with the colored area in lilac and blue, respectively for the first and second chart, refer to the first actual opening year of the two subway lines and, also in this case, we notice a correspondence in the trend of all the indices considered, in support of what has just been outlined in the previous point.

5 Conclusions

In conclusion, this study commenced with a theoretical examination of the potential advantages and disadvantages associated with the introduction of new subway lines in urban environments. We explored the sociological impacts of new subway lines, emphasizing both positive and contentious aspects. Subsequently, we defined the concept of a smart city, highlighting dimensions we considered most relevant to defining urban smartness. By focusing on several key variables related to these dimensions, we theoretically formulated a smartness index. Following this, we progressed to a more technical phase, employing scientific and mathematical methods to develop coherent indices from the available data. This process involved constructing our indices based on geospatial information to ensure alignment with territorial specifics. After meticulously defining these indices, we conducted multiple analyses that yielded significant insights.

The analysis specifically examined the impact of the new M5 and M4 subway lines on the smartness of Milan's neighborhoods. It was apparent that the introduction of new subway lines significantly influences all considered indices within the neighborhoods they intersect. Initially, the immediate effect of the subway line introduction can lead to increased property prices and a decrease in the diversity index, thus slowing the growth of the smartness index. However, over the study period, neighborhoods served by the subway ultimately exhibited higher levels of smartness compared to those without such services. This suggests that, despite initial challenges, the introduction of a new subway line can promote long-term benefits for the overall development of a neighborhood and the city as a whole.

We observed a fascinating trend in the smartness index from the construction phase to the operational phase of the analyzed subway lines. This trend could provide valuable insights for studying potential future developments in the affected neighborhoods.

It is essential to consider the multifaceted positive and negative aspects of introducing new subway lines. Efforts should be made to preserve diversity, regulate real estate price increases, and enhance urban greenery where necessary to improve neighborhood smartness. Furthermore, the establishment of new subway stops significantly benefits previously underserved neighborhoods, integrating them more fully into the city's framework. This integration helps reduce internal divisions in terms of growth and development, including economic aspects. Accessibility emerges as a crucial factor driving the enhancement of neighborhood smartness.

In summary, while the introduction of new subway lines presents initial obstacles, the long-term advantages for urban development and smart city initiatives are considerable. This study highlights the importance of thoughtful planning and implementation in urban transportation projects to maximize their positive impact on city smartness and livability.

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