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The state of the art of Smart City projects in Europe and Italy

TESI DI LAUREA MAGISTRALE IN
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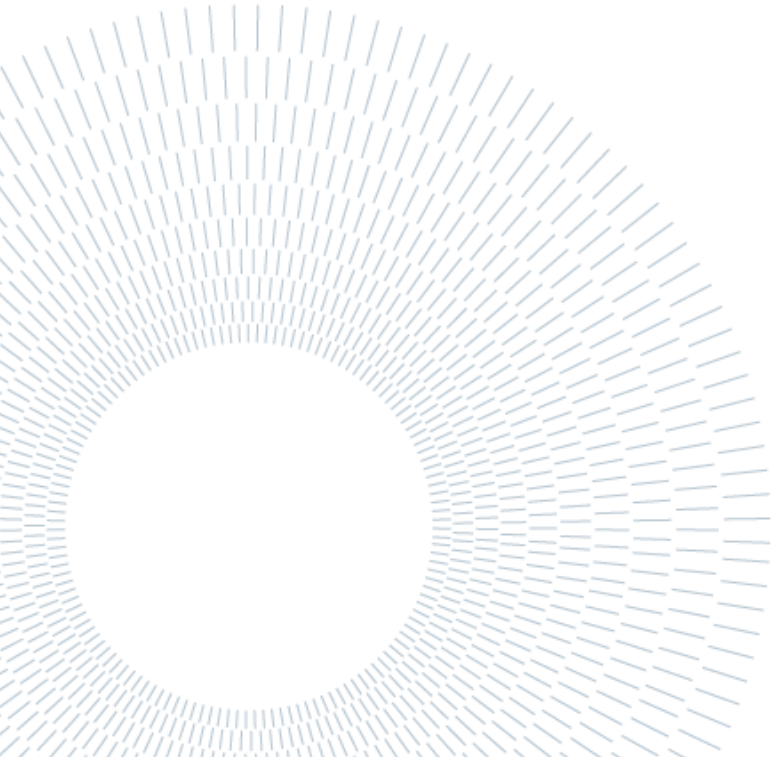

Abstract

The topic of Smart Cities is of crucial importance nowadays, as population growth and urbanization make it increasingly necessary to find solutions to urban problems such as pollution, traffic, and resource management. In this context, technology plays a fundamental role. The purpose of this thesis is to provide a detailed overview of the state of the art of Smart City projects in Europe and Italy. To achieve this goal, the first part of the research focuses on an in-depth analysis of the literature related to the concept of Smart Cities and their enabling technology, the Internet of Things (IoT), exploring the most important applications in this context. This allows for a detailed understanding of the topic and its technological implications. To map the current situation in Europe and Italy, a comprehensive database containing essential information on various types of projects was created for subsequent analyses. The analyses conducted revealed temporal trends, the geographical distribution of projects, and the main application fields on which they focus. Special attention was given to the topic of investments, also exploring the role of the European Union in promoting initiatives. Furthermore, the most relevant technologies employed in the projects were examined, highlighting the obtainable benefits, the United Nations' Sustainable Development Goals (SDGs) most frequently considered, and how data is utilized and leveraged to extract value. Another theme addressed in the thesis is citizen engagement, analyzing how active citizen participation is encouraged and integrated into Smart City projects. At the end of the analysis, it is possible to clearly understand the direction in which countries are moving through the types of projects they are most interested in, thus gaining a comprehensive understanding of the topic and the current situation.

Key-words: Smart City, Internet of Things, Application Fields, Sustainable Development Goals, Projects, European Union.

Abstract in italiano

Il tema delle Smart City è di cruciale importanza oggi, in quanto la crescita della popolazione e l'urbanizzazione rendono sempre più urgente trovare soluzioni ai problemi delle città, come l'inquinamento, il traffico e la gestione delle risorse. In questo contesto, la tecnologia gioca un ruolo fondamentale. Questa tesi ha infatti, l'obiettivo di delineare lo stato dell'arte dei progetti Smart City in Europa e in Italia. Per raggiungere questo obiettivo, la prima parte della ricerca si concentra su un'analisi approfondita della letteratura relativa al concetto di Smart City e alla sua tecnologia abilitante, l'Internet of Things (IoT), esplorando le applicazioni più importanti in questo contesto. Questo permette di fornire una comprensione dettagliata del tema e delle sue implicazioni tecnologiche. Per mappare la situazione attuale in Europa e in Italia, è stato creato un ampio database contenente informazioni essenziali su progetti di vario tipo per le successive analisi. Le analisi condotte hanno rivelato trend temporali, distribuzione geografica dei progetti e i campi applicativi principali su cui questi si concentrano. Un'attenzione particolare è stata dedicata al tema degli investimenti, esplorando anche il ruolo dell'Unione Europea nel promuovere iniziative nell'ambito delle Smart City. Inoltre, sono state esaminate le tecnologie più rilevanti impiegate nei progetti, evidenziando i benefici ottenibili, gli Obiettivi di Sviluppo Sostenibile delle Nazioni Unite più frequentemente considerati e come i dati vengono utilizzati e valorizzati. Un tema cruciale affrontato nella tesi è stato anche quello del coinvolgimento del cittadino, analizzando come la partecipazione attiva dei cittadini venga incoraggiata e integrata nei progetti di Smart City. Al termine delle analisi, è possibile chiaramente comprendere in che direzione si stanno muovendo i paesi attraverso le tipologie di progetti maggiormente predilette, avendo così una comprensione a tutto tondo del tema e della situazione attuale.

Parole chiave: Smart City, Internet of Things, Campi Applicativi, Obiettivi di Sviluppo Sostenibile, Progetti, Unione Europea.

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EXECUTIVE SUMMARY OF THE THESIS

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1. Introduction and Literature Review

According to Bowerman et al., a smart city is defined as a place where *"all structures are designed, constructed, and maintained using advanced, integrated materials, sensors, electronics, and networks, all interfaced with computerized systems that include databases and algorithms for tracking and decision-making"* [1]. This definition highlights the deep interdependence between Smart City and technologies. Therefore, a section of this chapter is devoted to a detailed analysis of IoT technology, particularly within the smart city context, followed by another section that focuses on exploring the broader theme of smart cities.

1.1. Internet of Things, the backbone technology of the smart city

The Internet of Things (IoT) is a critical technology for implementing a variety of projects within smart cities and is closely linked to the concept of *smart objects*. These are real-world objects capable of communicating and interacting with each other and their surrounding environment via the internet. To function effectively, these objects must possess essential properties such as *identification* and *connection* and are equipped with sensors, microcontrollers, data storage capabilities, and analytical skills. The ultimate goal is *ubiquity*: to create an ecosystem that is always and everywhere connected. Focusing on the IoT architecture, building blocks include smart objects, gateways, network infrastructure, and cloud infrastructure. Data collected by sensors are pre-processed by gateways, which then send data through the network infrastructure to the cloud, where storage and analysis functions are crucial [2].

In the specific context of a smart city, a five-layer IoT architecture has been proposed by Syed et al.[3]. The first layer, the *sensing layer*, consists of smart objects that gather data from the external environment. The second layer is the *network layer*, essential for managing the direction and flow of data within the network. In this layer, it is vital to consider the various communication technologies available, which vary in terms of data rate, coverage distance, and energy consumption. Protocols such as NFC, Z-Wave, and Zigbee cover short distances, while LoRaWAN, SigFox, NB-IoT, and 5G can cover much larger distances. These protocols are designed to minimize energy consumption to extend the life of smart objects, although 5G allows for very fast data exchanges at the cost of higher energy consumption. Moreover, in the network layer, gateways play a crucial role as intermediaries between the sensing layer and the middleware, where data processing occurs. In fact, in the *middleware layer*, the fourth one, data is transformed into useful information through cloud

computing, which allows for complex analyses and is the center for processing and storing data from smart objects. Following the middleware, there is the *application layer*, which connects users through applications with useful functionalities like analyzing data on air quality. The final and fifth layer is the *business layer*, where the main functionalities support decision-making through the creation of business strategies and the production of graphs based on data from the application layer. It is important to note that the cloud is the main processing hub, but the huge volume of data flowing into it can slow down operations and create bottlenecks. For this reason, technologies like fog and edge computing are moving computational capacities closer to the sensors themselves, optimizing operational efficiency.

Clearly, IoT is not the only technology employed in the smart city context, but it is often combined with other crucial complementary technologies like Big Data and Artificial Intelligence (AI). In particular, AI has been gaining increasing importance in recent years and through algorithms of machine learning, natural language processing, and computer vision, it significantly optimizes the analysis and prediction processes on the enormous amount of data coming from smart objects. Indeed, these types of technologies reduce human errors, ensure 24/7 availability, and allow for the performance of repetitive daily operations, leading to unbiased decisions in extremely shorter times.

Economically, the IoT market in Europe currently counts revenues of $65.1 billion, with expectations set for a significant increase to $122.7 billion by 2030. This forecast highlights a market that is thriving and expanding rapidly due to a wide array of applications.

1.2. The Smart City

The global population today is estimated at 8.1 billion people, with projections expecting growth to 9.7 billion by 2050. Coupled with the fact that about 55% of people currently live in cities, and an anticipated 68% will reside in urban areas by 2050, numerous challenges need to be addressed and resolved. These include high pollution levels, traffic congestion, overcrowding, higher crime rates, large volumes of waste, and crises in energy resource management and transportation.

To tackle these challenges, the advent and maturation of technologies such as IoT and AI have facilitated the expanding development of the Smart City paradigm. Smart Cities, as described by Gracias et al., *"use digital technologies, communication technologies, and data analytics to create an efficient and effective service environment that improves urban quality of life and promotes sustainability"*[4]. Again, the role of technology is emphasized, but it is accompanied by the primary goal of improving the quality of life for citizens in a sustainable manner, safeguarding the environment, and optimizing resource use.

What's fascinating to explore are the application fields of projects, identifying eleven key areas that effectively cover any aspect that can be optimized at the urban level. These areas include Smart Mobility, Smart Lighting, Smart Waste Management, Smart Environmental Monitoring, Smart Agriculture, Smart Building, Smart Metering & Grid, eHealth, Smart Security, Smart Tourism, and Smart Governance.

The primary objectives driving these projects are to enhance the quality of life, promote sustainability, and improve operational efficiency by managing limited resources more intelligently. However, there are also challenges faced in these types of projects, such as high implementation costs, privacy and security issues, problems with citizen adoption, data heterogeneity from myriads of sensors, and managing the quality of available data.

In 2015, 193 member states of the United Nations adopted an agreement known as the 2030 Agenda for Sustainable Development, defining 17 Sustainable Development Goals (SDGs) focused on themes such as commitment to sustainable progress, reaffirming the importance of sustainable economic growth, social inclusion, and environmental protection, all within a framework of international peace and cooperation. Particularly interesting is that one of these goals, SDG 11 (*Sustainable Cities and Communities*) is specifically focused on cities, making it highly relevant to the theme of smart cities. Moreover, other goals such as SDG 3 (*Good Health and Well-Being*), SDG 6 (*Clean Water and Sanitation*), SDG (*Affordable and Clean Energy*), SDG 9 (*Industry, Innovation and Infrastructure*), SDG 12 (*Responsible Consumption and Production*), SDG 13 (*Climate Action*), and SDG 17 (*Partnership for the Goals*) have also been identified as particularly relevant for smart city projects through detailed analysis conducted by various scholars in the field [5].

Another interesting topic which has been explored is how funding for smart city projects happens at the European level, finding out that it is facilitated through various comprehensive multi-year framework programs such as Horizon 2020 and Horizon Europe. Horizon 2020, a European Union program operational from 2014 to 2020, allocated about €80 billion to research and innovation, focusing on scientific excellence, industrial leadership, and societal challenges. Its successor, Horizon Europe, continued this effort with a budget of €95.5 billion for the 2021-2027 period targeting further advancements in technology and emphasizing ecological and digital transitions. Alongside these, the European Regional Development Fund (ERDF) plays a pivotal role in reducing regional disparities and fostering economic growth, Next Generation EU initiative acts as a temporary economic recovery tool designed to counteract the pandemic's impacts and EIT Urban Mobility, an initiative launched in 2019, seeks to transform urban transportation by optimizing the movement of people, goods, and waste within cities, supporting SMEs.
On an economic perspective, the smart city market registered a revenue of $29.78 billion in Europe in 2024, with forecasts suggesting a reachable value of $46 billion by 2028. Overall, this indicates an increasing trend and interest in Smart Cities which are increasingly gaining importance throughout Europe and are boosted by technological maturity.

2. Objectives and Methodology

The primary goal of the thesis is to map the state of the art of smart city projects in Italy and Europe, addressing various questions within this context.
The main research question is: *"What is the state of the art of Smart City projects in Europe and Italy?"*.
As a consequence, to address all the crucial elements related to the Smart City context, six derived research questions have been defined:

- RQ1: *"What is the temporal and geographical distribution of smart city projects in Europe and Italy, and which are the most developed application fields?"*
- RQ2: *"What are the main sources of investment for smart city projects, and how are these funds distributed among various application fields?"*
- RQ3: *"Which are the main technologies used in smart city projects?"*
- RQ4: *"How data are used in smart city projects?"*
- RQ5: *"Which are the main benefits of the projects, and which are the most impacted SDGs?"*
- RQ6: *"What is the degree of citizen involvement in smart city projects, and what forms does this involvement take?"*

To answer these questions, it was necessary to create a database containing the required information to conduct analyses. The database for this thesis was designed to match the columns of an existing database created by the Smart City Observatory of the Polytechnic of Milan, facilitating potential future integration between the two. The common columns include use case name, project name, investment description, total cost, investment typology, participants, city name, region, geographic area, nation, project extension, application field, functionality, progress status, start year, description, technology, and system integrator/provider. Additional columns were added to the new database to delve deeper into other topics such as benefits, European Union involvement, European Union funding source, data usage, data valorization, citizen engagement, and SDGs.
After creating the database, the research for projects to populate these fields began, focusing only on projects from 2021 to 2024 within the European and Italian contexts. By the end of the research period, which concluded in April 2024, 472 new projects were found.
Before proceeding with the analyses, standardization operations were necessary, handling empty cells with the term *N/A*, checking for accuracy errors and misspellings, managing the investment values of huge European Union initiatives, and organizing the SDGs and benefits columns to facilitate subsequent analyses. The standardization process was crucial since the main tool used, pivot tables in Excel, functions only when columns are correctly formatted with tags.
The next step was to merge the new database with that of the observatory, as some analyses were to be conducted on the combined data of these two databases. Since the new database was created with columns matching those of the observatory, the merging process was straightforward and quick. All projects from 2015 to 2022 in the observatory's database (867 projects) were integrated with the 472 new projects found, resulting in a total of 1339 projects for the period from 2021 to 2024.

The final step was to define what type of analyses to conduct and on which database. Specifically, two databases were used for the analyses: the new database created for this thesis with 472 projects from 2021 to 2024 and the merged database containing 1339 projects from 2015 to 2024.
Seven dimensions of analysis were defined to comprehensively answer the research objectives. These dimensions are:

1. Temporal, Geographical and Application Field
2. Investments
3. Technology
4. Data Usage and Valorization
5. Benefits
6. SDGs
7. Citizen Engagement

It is important to note that the first two dimensions of analysis used data from the merged database of 1339 projects to leverage the temporal depth of the data from 2015 to 2024, while the other analyses used only the new database of 472 projects from 2021 to 2024, revealing trends for the recent years.

3. Analysis and Results

The analysis dimensions previously described in the methodology are elaborated and explained in this chapter, demonstrating the most significant insights derived from them.

3.1. Temporal geographical and application field analysis

This analysis used the merged database containing 1,339 projects from 2015 to 2024, revealing a general growth in the number of projects at the European level, likely influenced by commitments made during the 2015 Paris Agreement, except for a significant decrease between 2019 and 2020 probably due to the pandemic. Post-2020, growth resumed, partly driven by European Union programs such as Next Generation EU and Horizon Europe. A similar trend was also observed in Italy, where the PNRR has played a crucial role in recent years.
At the European level, the application field with the highest number of projects was Smart Mobility, followed by Smart Governance and Smart Metering & Grid, likely due to these fields being broad with numerous facets in terms of implementations. For Smart Mobility, the most common functionalities were traffic and mobility management, followed by sharing and the growing use of Mobility as a Service (MaaS). In terms of Smart Governance, the most prevalent functionalities were digital twins and the digitalization of public administration. Concerning Smart Metering & Grid, there was an increased application in the electricity context, often including renewable energy sources such as photovoltaic panels and forming Renewable Energy Communities. Specifically, there was a significant spike in Smart Metering & Grid projects from 2020, largely because many EU initiatives focused on constructing positive energy districts.
In Italy, however, the application fields with the most projects were slightly different: Smart Mobility still saw the greatest interest, followed by Smart Metering & Grid and Smart Environmental Monitoring. Unlike Europe, Smart Governance ranked fourth, with the same number as Smart Lighting projects.
Exploring geographic trends, Italy emerged with the highest number of projects at 389, highlighting the country's interest in the smart city context but also indicating a clear data bias towards Italian territory due to easier access to project data. Along with Italy, the other three countries with the highest number of projects were Spain, Germany, and Finland with 114, 104, and 99 projects respectively, demonstrating their roles as pioneers.
A general look at the geographical distribution of projects showed that Western and Northern Europe had a significantly higher number of projects compared to Eastern Europe, which could be attributed to stronger economies and more developed industrial and technological hubs. In Italy, Lombardy was the most involved region with 82 projects, significantly more than the second highest, Lazio with 38 projects. This is consistent with Lombardy being the economic engine of Italy, and generally, most projects were conducted in Central and Northern Italy.
Considering the most active cities in smart city projects across Europe, Stockholm led with 37 projects, followed by Milan, Helsinki, Dublin, and Rome with project numbers ranging between 26 and 31. Surprisingly, two Italian cities were among the top five, which can again be explained by the research bias mentioned earlier. Overall, these cities are typically large metropolises where urban problems are more pronounced and companies focusing on innovation are more readily accessible.

3.2. Investments analysis

The investment analysis revealed that the majority of projects are funded by public entities, both at the European and Italian levels. This aligns with the fact that these projects are more focused on collective welfare rather than profits, resulting in smaller private investments.

Examining the allocated costs from public and private sectors and their combination (Public-Private Partnerships), it was noted once again that the majority of investments came from the public sector at the European level (€863.1 million - 68%), followed by public-private partnerships which accounted for about €406.7 million (32%). The private sector, however, only accounted for 1% of the total investment, showing a value of about €6.8 million. The analysis omitted €8.5 billion from PPPs because of a 2024 project in Greece, The Ellinikon, which plans to develop a smart city in Athens. This reflects a rising interest in public-private partnerships that combine resources and risks from both sectors

In Italy, the public sector still received most of the funds, but, unlike Europe, there was a significant 37% in private investments mainly due to companies such as A2A invested substantial sums in Smart Metering & Grid and Smart Waste Management projects. Public-private partnerships accounted for about 19% of the investments.

It was also interesting to explore the total costs allocated to different application fields, noting that Smart Metering & Grid received the most funding (€1.8 billion), followed by Smart Mobility (€1.5 billion). Analyzing the average cost of projects by application field, it was revealed that Smart Metering & Grid projects were the most expensive, averaging nearly €12 million per project.

From a geographical point of view, the countries that invested the most were Italy (€4.5 billion), England (€273 million), and Ireland (€174 million). The significant imbalance in these values is due to the fact that 75% of the available data on project costs were recorded exclusively in Italian territory, with Lombardy investing more than €1 billion.

All insights expressed so far have been derived from the merged database of 1,339 projects from 2015 to 2024, however, only the database with 472 projects from 2021 to 2024 was used to conduct an analysis solely on the funding sources of the European Union. This analysis found that the fund with the highest allocated costs was Next Generation EU with €869 million invested, all directly from the Italian PNRR. Significant amounts were also detected for Horizon Europe and Horizon 2020, with €145.2 million and €60.7 million invested, respectively. This demonstrates a clear interest of the European Union in helping to develop smart city projects.

Focusing on the Italian PNRR, it mainly funded projects in Smart Building, Smart Mobility, and Smart Metering & Grid, while Horizon 2020 and Horizon Europe framework programs primarily focused on promoting Smart Metering & Grid projects. Indeed, several projects aimed at creating Positive Energy Districts (PEDs) were funded through these programs.

3.3. Technology Analysis

The technology analysis, like all subsequent analyses which will be presented in this thesis, was conducted solely on the database of 472 projects specifically created for this study, covering the last four years. IoT emerged as the predominant technology in smart city projects, representing 36% of applications and serving as the infrastructural backbone by integrating various sensors and communication technologies such as LoRaWAN. Artificial Intelligence was the next most significant, accounting for 29% and enhancing automated and timely operations across domains such as traffic and energy management. Big Data and Cloud Computing were also critical, constituting 21% and 12% respectively, essential for managing and analyzing vast amounts of data. Additional noteworthy technologies included digital twins for simulating urban planning processes, photovoltaic panels for sustainable projects, and the emerging use of drones in logistics and monitoring.

3.4. Data Usage and Valorization analysis

The largest share of data, 54%, was used *to provide services to citizens*. This aligns with the smart city concept of enhancing resident quality of life by introducing new services and optimizing existing ones. Another 28% of data was used for *sharing with public or private stakeholders*, indicating a growing trend of collaborative service delivery. The smallest portion, 18%, was allocated *for internal purposes*, meaning improving internal processes.

Data valorization further illustrated that 63% of data was used in a *prescriptive* way to optimize

decision-making, while *adaptive* valorization accounted for 17%, enabling real-time, flexible decision-making supported by artificial intelligence.

3.5. Benefits analysis

This analysis illustrated a strong emphasis on the benefit *"environmental sustainability, reduction in pollution, and CO2 emissions"*, reached in 72% of projects, indicating a global commitment to sustainable urban development. *"Well-being, health, and citizen experience improvement"* was noted in 50% of projects, enhancing quality of life through integrated urban services. *"Operational efficiency and cost reduction"* was another significant benefit, present in 39% of projects, showcasing the role of smart technologies in optimizing city operations. *"Data-driven urban planning"* appeared in 37% of projects, emphasizing the use of data for strategic resource management and urban development. Finally, other benefits such as *"Mobility and traffic improvement"* and *"Optimization of resource management"* reflected lower percentages since related to specific sectors.

3.6. SDGs analysis

In this analysis, the data demonstrated strong support for several United Nations' Sustainable Development Goals (SDGs). SDG 11 (*Sustainable Cities and Communities*) and SDG 3 *(Good Health and Well-being*) were the most frequently targeted, each achieved in approximately 90% of the projects. These figures underline the central focus of smart city initiatives on enhancing urban sustainability and improving health outcomes.

Additionally, SDG 9 (*Industry, Innovation and Infrastructure*) and SDG 13 (*Climate Action*) also showed high achievement frequencies around 60%, reflecting the emphasis on utilizing innovative technologies and addressing climate change in smart city strategies. Other SDGs were less frequently addressed, with SDG 17 (*Partnership for the Goals*) achieving a 30% frequency, indicating the collaborative nature of these projects. SDG 7 (*Affordable and Clean Energy*) and SDG 12 (*Responsible Production and Consumption*) were also targeted, though at lower frequencies of 21% and 18%, respectively, often in projects specifically related to smart metering & grid and waste management.

3.7. Citizen engagement analysis

The analysis of smart city projects spanning from 2021 to 2024 revealed a growing focus on citizen engagement, with active participation observed in 49% of the projects. Over these four years, involvement progressively increased, reaching its peak in 2023. The slight decrease noted in 2024 is attributed to the data collection ending in April of that year, suggesting that by the end of 2024, the level of citizen engagement could surpass that of 2023. Various methods are employed to facilitate this engagement, including workshops, real-time feedback through mobile apps, participation in surveys and testing new solutions. These approaches highlight a shift towards more participatory urban governance.

4. Conclusions

In conclusion, the thesis provides a detailed analysis of smart city projects across Europe, especially Italy, from 2015 to 2024, highlighting a significant increase in projects, influenced by events like the Paris Agreement, the UN's SDGs, and the Covid-19 pandemic. Key areas of focus have been Smart Mobility, Smart Governance, and Smart Metering & Grid, with notable advancements in digital and sustainable urban infrastructure driven by EU initiatives like Horizon Europe and the National Recovery and Resilience Plan. The study reveals strong public sector involvement in funding, complemented by an increasing interest in public-private partnerships. Technologies such as IoT and AI have been crucial, enhancing urban management and operational efficiency. The projects predominantly support SDGs related to sustainable cities, well-being, innovation, and climate action, with rising citizen engagement indicating a shift towards more inclusive urban development.

Concerning the limitations of this thesis, they were closely linked to the data sources used, which primarily focused on European smart city projects, particularly from Italy. This focus was driven by the ease of accessing information in the native language and the concentration of existing resources. Another significant challenge encountered was the lack of detailed investment data, which was predominantly specific to Italy, limiting the scope of financial analysis.

Regarding future development trends in smart cities, the fact that 50% of projects are pilot projects and 45% are executive ones indicates a growing interest in innovative solutions. Pilot projects test technologies on a small scale, while executive projects expand these technologies on a broader level. Looking ahead, the Horizon Europe Strategic Plan 2025-2027 outlines key focus areas including Green Transition aimed at zero carbon emissions by 2050, Digital Transition to boost competitiveness with an emphasis on artificial intelligence, and fostering a more resilient, inclusive, and democratic Europe. The plan envisions innovations in energy and mobility targeting climate neutrality, increased use of renewable energy sources, and enhanced energy efficiency. It also stresses the importance of integrating digital technologies and AI in urban management, predicting growth in smart mobility and smart metering. The strategy promotes an inclusive approach to urban planning, suggesting increased citizen engagement in smart city projects moving forward.

Finally, future research should aim to extend the scope of analysis globally, striving for a more comprehensive collection of investment data and a broader observation of smart city financing. The continuous emphasis on Sustainable Development Goals is likely to expand the impact on a broader array of these goals, contributing to the creation of more sustainable, efficient, and livable urban environments. This approach will not only enhance the geographical and thematic breadth of the research but also provide a richer, more accurate picture of global smart city initiatives.

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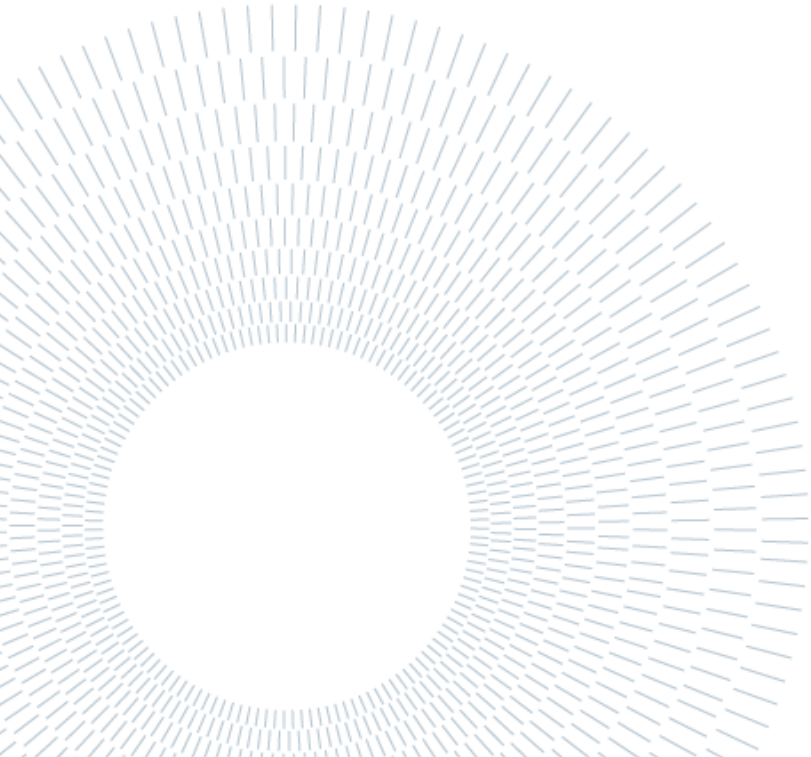

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1 Introduction and Literature Review

This chapter aims to rigorously explore the Smart City concept, placing particular emphasis on the technology that constitutes its backbone: the Internet of Things (IoT). Through an in-depth analysis of the scientific literature, the intention is to highlight many aspects that interconnect these two areas, underscoring how complex it is to discuss one without mentioning the other. This intrinsic link guides the approach adopted in the chapter, which includes an initial examination of the IoT as the technological foundation of smart cities, and then goes into specific detail on the Smart City paradigm. In *Figure 1* the content of the chapter is summarized in a single scheme.

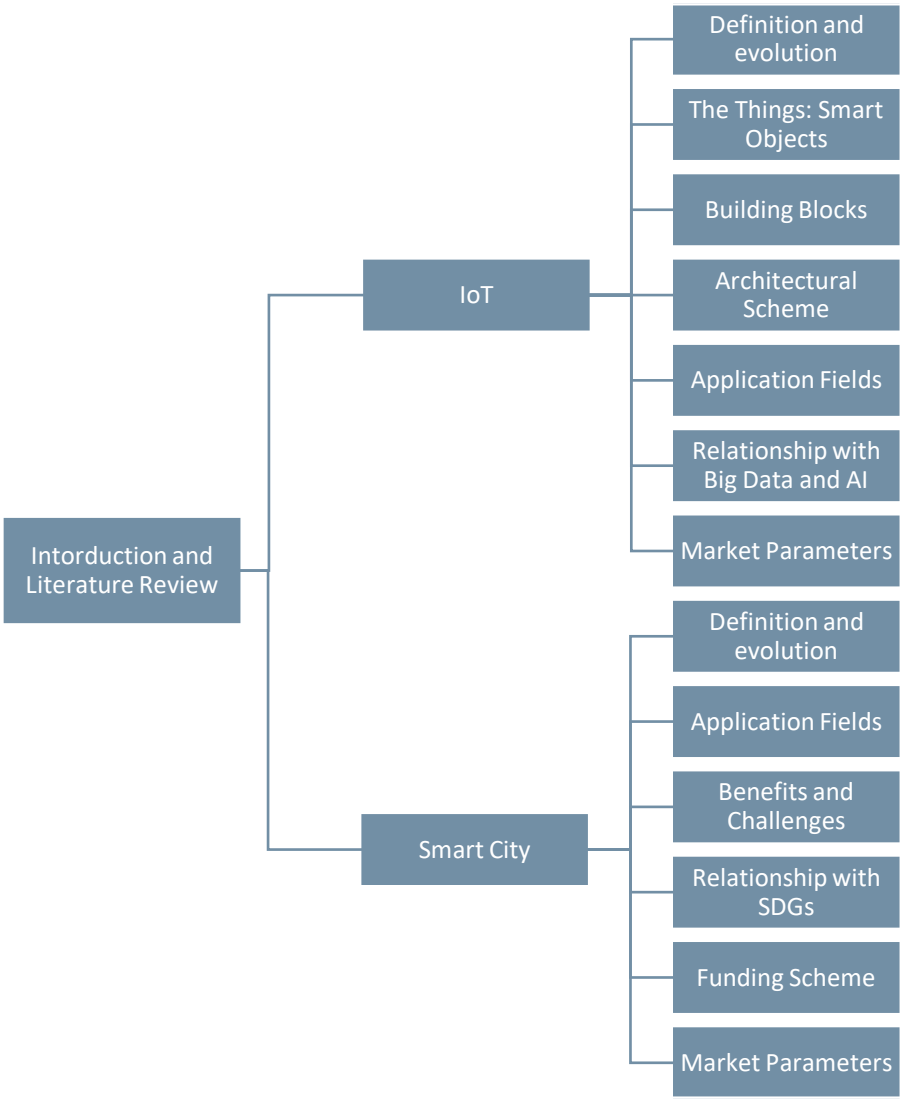


Figure 1: Introduction and Literature Review contents

The first section is dedicated to the IoT, starting with its definition and then exploring the structural and architectural elements that characterize it. The applications permitted by this technology and its relationship with advanced concepts such as Big Data, Artificial Intelligence, and Cloud Computing, now complementary and indispensable to the IoT, are explored in depth. This analysis is completed with an overview of the market parameters, illustrating the evolution and economic value generated by the IoT, with a specific focus on implementation in urban settings, thus making the contents relevant and functional to understanding the smart city context.

In the second section, the focus shifts to Smart Cities: definitions and application areas are outlined, pointing out how technological solutions can improve urban life. Related benefits and challenges are presented, without neglecting the important correlation between smart cities and sustainability, also revealed through the United Nations Sustainable Development Goals. This part is enriched with the funding and financing scheme most used in the Smart City projects realm, finally providing insights into the current situation and future projections of a constantly growing market, highlighting the strategic importance of smart cities in the contemporary technological and social landscape.

Therefore, the research questions that this chapter aims to address are:

- *What is a Smart City and what are the key themes associated with it?*
- *What are the key enabling technologies for the Smart City ecosystem?*

The entire literature analysis was conducted using scientific articles from Google Scholar and Scopus repositories. The selected scientific articles included reviews, articles, conference papers, book chapters, and journals. However, to integrate information and obtain updated and reliable data on topics such as IoT and Smart City market values, websites were also used.

1.1. Internet of Things, the backbone technology of the smart city

In the contemporary era, technology and automation are profoundly redefining the way of living, pushing more and more towards a digital existence. The Internet and wireless networks are at the center of this revolution, radically changing how daily activities are approached [1].

The Internet has evolved through several key phases, each introducing new ways for people and technology to interact. Initially, before the widespread use of the Internet, communication relied on landlines and text messages (SMS), which were the height of

technology at the time. Then came the Internet of Content phase, where it became possible to send longer messages, like emails with attachments, opening up a world of information and entertainment, significantly expanding what could be done online. Following this, the Internet of Services phase focused on digital applications such as online productivity tools and e-commerce making it possible to do almost anything online, from shopping to managing finances, all from a computer. Next, the Internet of People phase emerged, where social media platforms like Facebook, Skype, and YouTube made it easier for people to connect in ways that were once unimaginable, making the world feel smaller. The current phase is known as the Internet of Things (IoT), where not only are people connected to the Internet, but everyday objects as well. This includes devices that can communicate among themselves and with users, introducing an unprecedented level of automation and interactivity [2].

It is evident during this evolutionary path how in the past, interacting with technology meant direct and often laborious involvement by people, with long lead times for any task. The direction taken in the latest stage, on the other hand, aims to make these interactions simpler and more efficient, favoring communication between devices to lighten the human workload. The Internet of Things (IoT) promises to revolutionize intelligent systems enabling real-time monitoring and analysis of data in a variety of contexts, marking a turning point in the interaction with technology in everyday life [1].

One of these contexts is the Smart City, in fact, to comprehend better this subsection a brief definition of this concept is needed. An interesting one is given by Bowerman et al.:

"In a Smart City, all structures should be designed, constructed and maintained, making use of advanced, integrated materials, sensors, electronics and networks that are interfaced with computerized systems comprising databases and tracking and decision-making algorithms" [3].

As shown by the definition, it's nearly impossible to discuss Smart Cities without mentioning terms such as "sensors" and "networks". This is primarily because IoT serves as the backbone of the smart city, enabling ubiquitous connection and communication of many physical items critical to make cities more efficient, sustainable, and livable [4].

1.1.1. Definition and evolution

The foundational idea of IoT was first introduced in the early 1990s with the very first IoT application, the Trojan Room coffee pot in 1993, a coffee pot in the University of Cambridge that was monitored via the world's first webcam to avoid empty trips to the coffee room. That same year saw the development of the first Internet-controlled device, a toaster that could be switched on and off remotely via the Internet, marking

significant milestones in IoT evolution. The term Internet of Things, however, was first introduced by Kevin Ashton in 1999, when he was working with the Auto-ID Center at the Massachusetts Institute of Technology (MIT) to develop a network of objects using Radio-frequency Identification (RFID) [2], [5]. In 2005, the foundation of modern smart home technology was laid with the introduction of Nabaztag. This early iteration of the smart home assistant, shaped like a rabbit, could provide updates about the weather, stock market fluctuations, and RSS feeds, resembling the functionalities of contemporary devices such as Alexa and Google Home. The timeframe between 2008 to 2009 is acknowledged as the formative period of the Internet of Things (IoT), since as Cisco IBSG stated, the number of devices connected to the Internet exceeded the global human population [5], a trend that continued till present day in which the number reached more than 15 billion [6]. Between 2013 and 2014, the realm of IoT devices experienced a significant advancement with the integration of sensor technology. Devices like thermostats and home lighting systems began to incorporate sensors that could precisely gauge the environment, thus facilitating remote home management through smartphones. Finally, 2014 marked the inception of the first "Smart City" with the establishment of Smart Docklands in Dublin, testing state-of-the-art technological solutions aimed at addressing urban challenges. Among the innovations, intelligent waste disposal bins and sensors designed to monitor flood levels as well as noise pollution were tested [5].

Coming to a definition of IoT, it can be described as the integration of real-world objects, defined “smart objects” with advanced technologies to enable them to communicate and interact with each other and with the external environment, using the Internet as a means of connection. These objects, transformed into nodes in a network, actively participate in the exchange of data, sending and receiving information. They are equipped with sensor devices, microcontrollers, communication systems, and data storage, retrieval, and analytics capabilities, contributing to the creation of an integrated and synergetic network. This allows each element of the IoT ecosystem to be connected efficiently, enabling a wide range of intelligent and automated applications [1].
The goal is clearly *ubiquity*, which translates in making the entire ecosystem always connected and everywhere. Moreover, this definition outlines the main elements belonging to the paradigm such as smart objects, communication technologies, analytical capabilities, and architectural schemes for the interaction of these devices. These concepts being the main building blocks of the IoT will be explored in the following subsections.

Finally, the IoT model can be summarized in 5 crucial principles that guide its development and implementation:

- **Distributed Environment:** the IoT operates in highly distributed contexts, where data is collected from a variety of sources. Subsequently, this data is

processed by different intelligent entities in a distributed manner, enabling a wide range of real-time analysis and reactions across multiple points in the network [7].

- **Interoperability:** it is essential that IoT devices produced by various vendors can communicate with each other to achieve common goals. This requires the design of standards, protocols, and systems that facilitate the exchange of data so that smart devices from different brands can interact unhindered [7], [8].
- **Scalability:** billions of objects are expected to be integrated into the IoT ecosystem, which implies that applications and systems operating in these environments must be capable of handling and processing massive amounts of data, ensuring consistent performance even as the number of connected devices increases exponentially [7], [8].
- **Scarcity of resources:** computing units and energy are considered particularly limited resources. This implies a challenge in optimizing the use of these resources to ensure the operability and efficiency of IoT devices, even in intensive usage scenarios. IoT device have limited battery power, so it is essential to use them in the most efficient way, considering both communication and processing tasks [7], [8].
- **Security and personal privacy:** users' perception of feeling helpless and vulnerable in the face of control by unfamiliar external devices can be a serious barrier to IoT adoption. Moreover, vast amounts of personal information, often transmitted over potentially insecure networks are generated and therefore one of the main privacy risks stems from the fact that many users are not fully aware of the data collected by their IoT devices, how this data is used, who it is shared with, or how well it is protected. In this context the risk of cyber attacks is tangible[7], [8].

1.1.2. The Things: Smart Objects

Smart objects fundamentally transform everyday items (cars, traffic lights, machinery, cameras lights and many others) by incorporating sensors, actuators, and processors. Sensors are devices capable of interacting with the environment to measure various environmental parameters such as motion, temperature, humidity and more. On the other hand, actuators are devices designed to alter the state of the external environment, similar to how a temperature controller operates in an air conditioning system [2]. In order to be effectively defined as “smart”, these objects must be characterized by several properties, as defined by the Internet of Things Observatory of the Polytechnic of Milan [9]:

- **Identification:** each object must have a unique identifier in the network of connected objects so that it can be uniquely recognized. It is basically a code or

an ID. Since the number of devices in the IoT paradigm is enormous, it is important that each of them can be managed and contacted precisely and unambiguously.

- **Connection:** the fundamental condition is to be connected to a network, enabling communication, and exchanging of data with other objects. In fact, this characteristic is directly indicated by the word Internet of Things itself. An example is represented by cars that can communicate their driving data to insurance companies or to various entities for traffic monitoring.
- **Metainformation:** information such as location and diagnostics of the object are part of this category. Concerning diagnostics, it is possible to detect the failure of the object when it is not working but also act in a predictive way, having the smart object communicating a possible risk of failure. An example is represented by industrial machinery.
- **Interaction with the surrounding environment:** this category includes sensing, metering, and doing actions. Sensing refers to the ability to measure typical environmental variables like CO2 levels in urban environments while metering is related to the tracking of electricity, water, or gas consumption, for example using smart meters. In addition, the ability to program these devices allows these objects to perform specific actions like streetlamps regulating the luminous intensity according to the environmental conditions.
- **Processing capability:** the presence of microprocessors inside these devices allows them to analyze data in real-time and send the most relevant ones. An example is represented by smart cameras that transmit data only if dangerous situations are detected.

Among these properties, only *identification* and *connection* are mandatory to define an object as "smart", while the last three are considered as additional and enriching functionalities.

As previously mentioned, all these objects are characterized by the inclusion of sensors because a fundamental feature of the IoT is *context awareness*, meaning the ability to understand the conditions of the external environment. Most sensors are small in size, cost-effective, and energy-efficient [10] and considering the smart city context, the most important to contribute to a sustainable urban environment, as defined by many literature papers, are:

- **Bio sensors:** these advanced sensors are at the heart of connected health technologies, enabling constant, real-time monitoring of various physiological parameters. From wearables that track heart rate, blood pressure, and body temperature to specialized medical devices that monitor blood glucose levels without the need for blood samples are included in this category [10], [11].

- **Motion sensors:** essential for security and navigation, these sensors can detect movement and provide accurate data on the location of people, vehicles, or other objects. They are widely used in home security systems, vehicle tracking applications, and logistics management, where accurately tracking the path of a package is essential [11].
- **Environmental sensors:** sensors that monitor critical parameters such as temperature, humidity and air quality, essential for both home comfort, industrial applications and urban environment in general [11], [12].
- **Agriculture sensors:** specializing in sensing plant growth conditions, these sensors help farmers monitor crop health and soil conditions, informing critical irrigation, fertilization, and harvesting decisions. Integration with automation systems can lead to significant efficiency and productivity gains [11].
- **Safety sensors:** from surveillance cameras that use facial recognition to identify authorized subjects, to smoke and gas detection sensors that can save lives by triggering alarms in the event of a fire, the range of sensors dedicated to security is wide and expanding [11].
- **Energy sensors:** by measuring energy consumption, these sensors enable more intelligent and sustainable energy management in residential, commercial, and industrial buildings. Analysis of the data collected can highlight energy-saving opportunities, helping to reduce costs and environmental impact [11], [12].
- **Water quality sensors:** vital for ensuring safe and healthy drinking water, these sensors analyze chemical and physical parameters such as pH, turbidity, and the presence of contaminants. They are also essential for monitoring aquatic ecosystems, providing valuable data for environmental protection [11].
- **Waste management sensors:** integrated into smart collection containers, they inform about the fill level and type of waste, optimizing collection and recycling. Monitoring the status of bins in real-time can radically transform the efficiency of urban waste management services [11].
- **Mobile phone-based sensors:** smartphones are equipped with a diverse array of sensors such as accelerometers, gyroscopes, cameras, microphones, GPS, light sensors, and proximity sensors, which are crucial for crafting IoT applications. These devices enable the detection and analysis of user movement, orientation, visual and audio inputs, location, ambient light levels, and the proximity of objects. Utilizing this sensor data, developers can create applications that monitor physical activity and predict specific behaviors, offering a comprehensive toolkit for understanding and improving human health and behavior [10].
- **Identification sensors:** RFID tags and NFC devices are characterized by unique identification and they are used for a variety of applications including secure transactions, data transfer in intelligent transport systems, object tracking, and inventory management [12].

1.1.3. Building Blocks

The Internet of Things (IoT) architecture, is built on four key building blocks [1]: *things*, *gateways*, *network infrastructure* and *cloud infrastructure*.

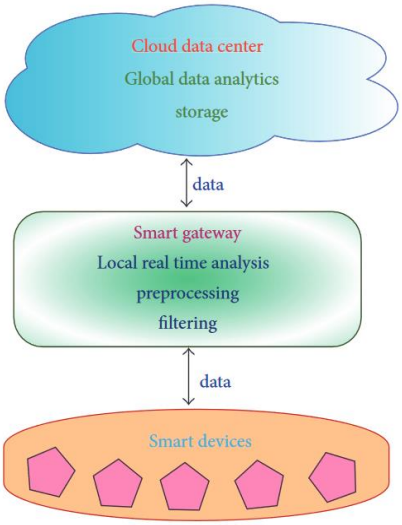


Figure 2: Smart gateway for preprocessing (Sethi & Sarangi)

Things, as discussed in the previous subsection, are smart objects embedded with actuators and sensors that can capture relevant information from the environment. *Gateways*, as represented in *Figure 2*, deliver networking services to IoT devices by acting as mediators between them and the cloud infrastructure. They perform a variety of roles, including sensor data collecting, initial processing, and cleaning. This serves as a preprocessing stage, ensuring that only the most relevant data are transmitted to the cloud for further analysis. Furthermore, these technologies monitor the energy consumption and operational characteristics of IoT devices while protecting the data's privacy and integrity [10]. *Network infrastructure* includes gateways, routers and communication technologies that manage data flow from things to the cloud and enable smooth operation in the ecosystem. Finally, *Cloud infrastructure* provides data storage and computational resources for data analysis and processing thanks to servers and data storage units, enabling decision-making on the collected information. The role of network communication technologies and cloud computing will be further analyzed in the next subsection.

1.1.4. Architectural Scheme

After having defined the basic elements of the Internet of Things, it is crucial to explore how IoT is implemented from an architectural point of view, especially in the smart city context. The key operations including data collection, exchange, and processing, which were highlighted earlier, play a vital role in this deployment. In the literature, many architectures have been reviewed passing from the basic three-layered models to more complex seven-layered designs. Among these, the five-layer architecture has emerged as the most favored and recurrent approach. This architecture, applied on a smart city, described by Syed et al. and depicted in *Figure 3*, encapsulates the critical dimensions of IoT, offering a comprehensive blueprint for its implementation, including the role of Cloud, Edge, and Fog computing [12].

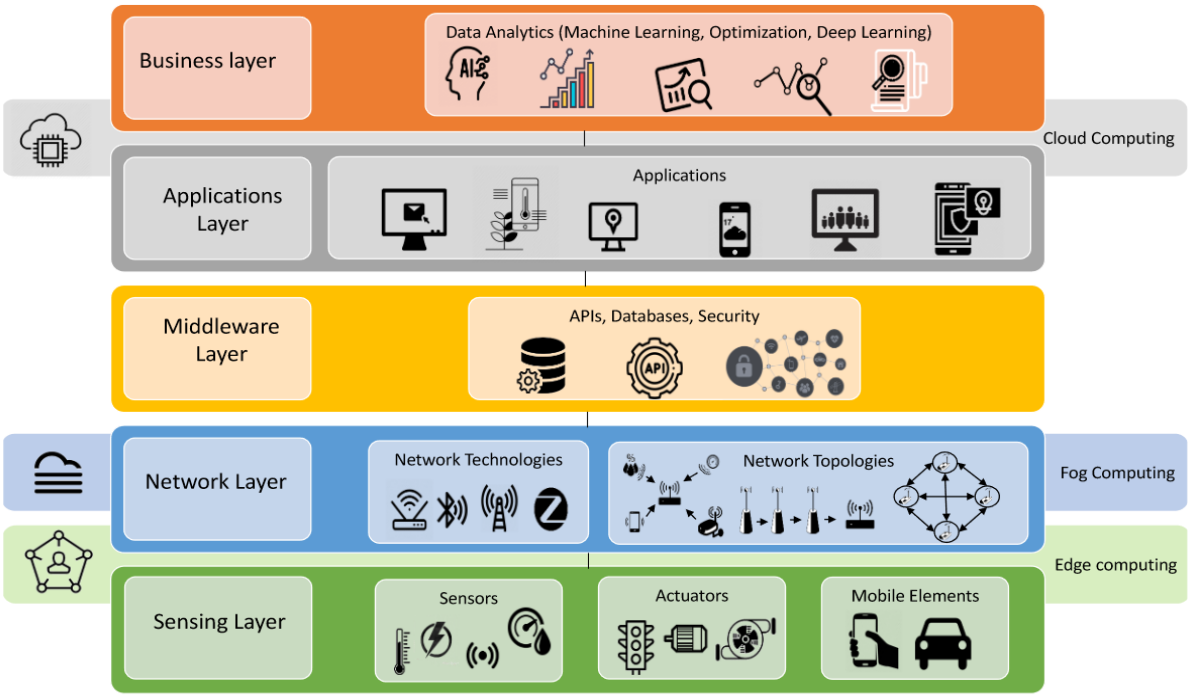


Figure 3: Five-layer IoT Architecture (Syed et al.)

1.1.4.1. Sensing Layer

Also known as *perception layer* [12], operates at the physical tier, using devices such as sensors and actuators incorporated in smart objects defined in *subsection 1.1.2*, to facilitate interaction with the real world. These devices communicate, collect data from the environment and communicate data back and forth through wireless networks [13]. The result is having a physical environment in urban areas where everything is connected from buildings to roads, to streetlights and people themselves.

1.1.4.2. Network Layer

Also known as *transportation layer*, is essential for managing the flow and direction of data across a network. It serves as the backbone for data routing and transmission, ensuring that information could be efficiently passed from one node to another. In this layer network, gateways play a pivotal role acting as intermediaries between the sensing layer and the middleware one [13]. In a smart city, millions of devices interact continuously, exchanging data in real-time, and therefore advanced communication solutions are required to manage an increasing volume of information exchange efficiently and securely. Wireless technologies play a crucial role in this context, offering the flexibility and scalability needed to support connectivity between heterogeneous devices [14].

Before understanding which are the main communication protocols used in the IoT domain, it is necessary to understand that networks can be structured in different ways, according to how nodes, namely the devices, are linked between them. Four main topologies can be defined [12]:

- **Point-to-Point:** devices are connected in line, one after another. If one device has a problem, the whole system could stop working. This setup is not very common in IoT because it's not very reliable.
- **Star:** all devices are connected to one central node, namely the gateway. They have to send all their messages through this central point, which can collect data easily but might experience bottlenecks if there are too many devices.
- **Mesh:** every device can talk to each other directly. This makes the system more flexible and reliable because if one device stops working, the others can still communicate.
- **Tree:** the tree topology network combines multiple star networks into a hierarchical structure, connected through a central bus, allowing for easy scalability and efficient management. It offers fault tolerance, as the failure of one node or branch does not necessarily disrupt the entire network, ensuring reliability. However, its hierarchical nature can lead to a single point of failure at higher levels, potentially impacting the whole network if the central node or primary connections fail [15].

Once explored the network topologies, it is now possible to introduce the main communication protocols that can be classified according to the area they cover, namely Home Area Networks (HANs), Field Area Networks (FANs) also known as Neighborhood Area Networks (NANs), and Wide Area Networks (WANs). HANs refer to a distance up to 1 km, FANs/NANs are linked to broader areas like neighborhoods reaching up to 10 km, while FANs are projected for wide distances even reaching 100 km [12], [16]. When classifying communication technologies, as shown in *Table 1*, fundamental parameters to consider include energy consumption,

data rate, and operative range, namely the coverage distance. Regarding energy consumption, it is important to note that all these technologies, as applied to IoT sensors, are designed to be low power to ensure that device batteries could have a long life. However, to compare technologies against each other, the categorization of low, medium, or high energy consumption is relative to the scale created for their comparison.

Home Area Networks

- *RFID:* Radio Frequency Identification is a cost-effective communication protocol that utilizes minimal energy to enable wireless communication between devices via radio frequencies. This system operates using specialized chips known as "tags", which are either battery-free or equipped with long-lasting batteries. These tags can transmit data only when in proximity to a device called "reader", which activates them using a magnetic field. RFID tags have an extensive lifespan, lasting for many decades, but can only transmit data when within close range of the reader: up to 10 meters for battery-free tags and up to 50 meters for those with a small battery [7]. The data transmission of this technology is typically up to 424 Kbps [17] according to the different frequencies used [18] and it is compatible with point-to-point network topologies. RFID is commonly used in unique identification applications such as automated toll collection, real-time location tracking, and inventory management [19].
- *NFC:* Near Field Communication is similar to RFID, but it works in a slightly different way. Instead of having tags and readers, both the things that want to communicate need to be powered and can send and receive data back and forth, enabling communication in both ways [12]. It works on a point-to-point topology network and it is a low-distance protocol since devices can communicate just a few centimeters apart, in a range of 20 cm [2]. The data transmission speed of this technology ranges from 106 Kbps to 424 Kbps [12] and it does not use much power making it perfect for battery-saving [7]. That is the reason why it is used frequently in smartphones in applications such as contactless payments.
- *Bluetooth:* it is an energy-efficient protocol allowing connection for a potentially endless number of devices. It is created for communication over short distances with minimal data flow, facilitating smooth entry and departure of devices within the network. Bluetooth uses the star network layout and operates with a rapid data rate transmission of up to 2 Mbps [12]. It is important to make a distinction between the devices using it, since they can be divided into masters and slaves. Master devices give commands and control while slave devices receive instructions and are designed to use as little energy as possible. They do

this by entering a "sleep mode" when not actively receiving instructions from the master. A typical example of a master device is the smartphone while devices including smart thermostats and smartwatches are categorized as slaves [7].

- *Z-Wave:* it is a low-power protocol created to facilitate home automation, indeed, the typical range is between 30 and 100 m [12]. Through this technology it is possible to send small amounts of data with transmission speeds of up to 200 Kbps and the preferred network topology is the mesh one. Smart lighting switches and other sensors for household appliances are the typical applications [7]. This kind of network can support up to 232 smart devices [20].
- *Wi-Fi:* it provides the possibility to exchange large amounts of data with a high data rate transmission up to 500 Mbps in the latest standards [21], but for this reason, it consumes higher levels of power. The range in which this protocol is used is up to 100-140 m and it uses the tree network layout [12], [22].
- *Zigbee:* it was created to be an affordable and energy-saving way for sensors to communicate with each other. It can send data at a low transmission rate of 250 Kpbs, within a range up to 100 m, and can support the use of star, mesh, and tree network topology [12]. This setup helps create a network that can cover a good area without using a lot of power or costing too much, making it suitable for many applications like smart homes with automatic lights and electrical meters. The application and characteristics of this network are similar to the Z-Wave unless the Zigbee can support up to 65,000 devices connected at the same time and offers better performance in terms of speed rate [20].
- *6LoWPAN:* this protocol uses the internet's own language, known as IP, and specifically uses the newer version of it called IPv6 [16]. It is a low-power communication technology meant for devices that do not need to communicate over long distances, between 10 and 100 m, and ensures a data rate up to 250 Kpbs, working on a mesh or star configuration. This kind of protocol is used in home automation and industrial monitoring applications [16], [23].

Field Area Networks/Neighborhood Area Networks

- *Wi-SUN:* it is a low-power network protocol designed for a longer range of communication compared to the ones previously described. Based on mesh or star topology, it can have a coverage of up to 4km and a data rate of up to 300Kbps. It is mainly used for managing utility services such as electricity and gas through energy sensors [12].

Wide Area Networks

- *LoRaWAN:* Long Range Wide Area Network is an unlicensed communication technology which specializes in enabling communication over long distances, ranging from 5 to 20 km, while keeping energy consumption minimal. In fact, an IoT device using this technology could experience more than 10 years of battery duration. It is characterized by the presence of multiple gateways forming a nested star topology and it has low data transfer speeds of up to 50 Kbps, since it is designed primarily for sending small data packets few times a day [12], [24]. It's widely used in large urban and rural areas with sensor applications like smart electricity metering, smart streetlight control, air quality, and healthcare patient monitoring [25].
- *SigFox:* it is a special communication method which works using unlicensed radio waves to send and receive very narrow and precise signals at slow data rates, namely 100 bps. Similarly to LoRaWAN, it enables to send information over really long distances, up to 50 kilometers [12]. However, being structured as a one-hop star topology network, SigFox offers a centralized path to the internet while LoRa offers a more flexible, scalable approach with its decentralized network of multiple gateways. For this reason, SigFox is tailored for basic tasks like tracking and monitoring through sensors while LoRaWAN is deployed in more complex applications related to smart cities [26].
- *NB-IoT:* Narrowband Internet of Things is a licensed communication technology operating on LTE frequency bands. It is a low-power, low-energy solution that can connect hundreds of thousands of devices at once [13]. It works in a range of up to 10 km, transmitting data with a maximum speed of 200 Kbps and its network topology is identified in the tree one [12]. Comparing this protocol with LoRaWAN, it consumes more power, it covers a less extended area and it is more reliable and interoperable since operating on a licensed spectrum [27].
- *Cellular:* Cellular communication technologies such as 3G, 4G and 5G are crucial for transferring large amounts of data over long distances (up to 100 km) at high speeds, reaching up to 599 Mbps [28] with the latest 5G generation. These protocols, characterized by a tree architecture, require more significant energy consumption levels. Unlike other wide-area networks that aim to minimize energy use, cellular networks are ideal for applications where energy consumption is not an obstacle and where real-time data is crucial, thanks to their low latency [12], [14]. In particular, the adoption of 5G technology in smart cities promises to revolutionize key areas such as traffic management, public safety, energy efficiency and healthcare. This is done through real-time traffic monitoring and management, rapid identification and intervention in case of risky situations, maximizing energy efficiency and improving healthcare

through telemedicine and remote patient monitoring. 5G technology acts as a catalyst, enabling the instantaneous collection and analysis of data, which in turn enables more efficient, safe, and sustainable urban services, contributing significantly to improving the quality of life in urban areas [29].

Table 1: IoT Communication Protocols

Technology	Classification	Maximum Range	Maximum data rate	Battery consumption	Network topology
RFID	HAN	10-50 m	424 Kbps	Low	Point-to-point
NFC	HAN	20 cm	424 Kbps	Low	Point-to-point
Bluetooth	HAN	240 m	2 Mbps	Medium	Star
Z-Wave	HAN	100 m	200 Kbps	Low	Mesh
Wi-Fi	HAN	140 m	500 Mbps	High	Tree
Zigbee	HAN	100 m	250 Kbps	Low	Mesh, Star, tTree
6LoWPAN	HAN	100 m	250 Kbps	Low	Mesh, Star
Wi-SUN	FAN/NAN	4 km	300 Kbps	Low	Star, Mesh
LoRaWAN	WAN	20 km	50 Kbps	Low	Nested star
SigFox	WAN	50 km	100 bps	Very-Low	One hop star
NB-IoT	WAN	10 km	200 Kbps	Low	Tree
Cellular (5G)	WAN	100 km	599 Mbps	High	Tree

1.1.4.3. Middleware Layer

Middleware is essentially a software that allows different applications and devices to work together, simplifying the complexities of smart objects [7]. According to Syed et al. this layer *"provides a generic interface for the sensing layer hardware and the Application layer which uses the data through various API's and database management services to provide users with services"* [12].

In essence, all the data collected by sensors are transmitted through different communication technologies, as described previously in the network layer, to the middleware layer, also known as processing layer. Here, the data are stored, inspected, and thoroughly analyzed. This process is vital within the IoT ecosystem because it transforms the raw data into valuable information. This information can then be used

in various applications, offering necessary services. To manage this effectively, the system leverages advanced technologies such as database systems for storing data, cloud computing for scalable processing capabilities, and big data processing tools for efficiently analyzing large datasets [10].

1.1.4.4. Application Layer

According to Al-Fuqaha et al. *"The application layer provides the services requested by customers. For instance, the application layer can provide temperature and air humidity measurements to the customer who asks for that data. The importance of this layer for the IoT is that it has the ability to provide high-quality smart services to meet customers' needs. The application layer covers numerous vertical markets such as smart home, smart building, transportation, industrial automation and smart healthcare"* [30]. This layer is the connection point with the users and implies cloud computing techniques through the middleware to provide them useful applications [12].

1.1.4.5. Business layer

It is also called management layer because it is in charge of coordinating the operations and services within the whole architecture. Its main functions include developing business strategies and creating visual representations like graphs derived from the data provided by the Application layer. Overall the business layer facilitates the decision-making process by utilizing extensive data analysis to improve the whole IoT ecosystem [12], [30].

1.1.4.6. Cloud, Edge, and Fog Computing

Cloud computing is an innovative technology that enables the storage and retrieval of data and applications through the internet. It permits access to a variety of computing resources and services, such as servers for data storage, networking infrastructure, analytical capabilities, and platforms for software development, all accessible via the Internet. This technology utilizes strategically positioned data centers globally, owned by the providers, to effectively deliver these services. The primary benefit of cloud computing lies in its capacity to offer scalable resources to a broad user base, in fact, individuals and enterprises can use high-performance computing services that would otherwise require significant investments such as the purchase of physical servers [31].

In Smart City applications, the cloud plays a crucial role. It acts as a centralized hub that can oversee, control, and analyze the large volume of data gathered by IoT devices spread throughout the city. It can conduct complex analyses, such as recognizing

patterns and trends in sensor data, which can enhance the intelligence and efficiency of cities. However, this model could experience drawbacks such as network congestion, which occurs when sensors frequently send data simultaneously, or latency issues, which arise from the physical distance separating sensors and the cloud, delaying decision-making processes. As IoT systems grow, ensuring network reliability becomes increasingly complex, with the vast amount of data transfer potentially compromising the system's efficiency [12].

To address these challenges, the fog computing model was introduced, shifting some processing capabilities closer to the data source (smart devices in the physical layer), at the network's edge. This model leverages the enhanced computational capabilities of local network devices, such as gateways, to perform preliminary data operations, thus reducing both the amount of data sent to the cloud and response time. This translates into benefits for applications that need real-time communication. Furthermore, fog computing addresses the issue of energy efficiency. Indeed, by processing data closer to its source, it limits the need for long-distance communications, helping to preserve the battery life of devices [7].

Finally, Edge computing advances the main idea proposed by the previous model by moving data processing functionalities directly to the IoT devices themselves, lightening the load on both fog and cloud layers. However, in this model, more elementary tasks are performed compared to the fog paradigm [12].

These three models, cloud, fog, and edge computing do not exclude each other but can be integrated and used complementarily within the same architecture, leveraging the unique strengths of each of them, creating a more resilient, efficient, and scalable network [12].

1.1.5. Application Fields

As a versatile foundation of contemporary innovation, the scope of IoT extends across a wide range of application areas. The most important ones are the following:

- **Home automation:** it enables the automated management of the household through sensing and remote control, thereby enhancing convenience and comfort in daily life. Routines can be established by sensors, particularly helping individuals with forgetfulness, and promoting energy efficiency by automatically powering off lights and electronic devices. Motion sensors, for instance, not only contribute to energy conservation but also strengthen security measures by detecting potential intrusions. Various sensors gather environmental data including light levels, temperature, humidity, and the

presence of gas or fire, enabling tailored responses to specific situations. For example, the system might trigger the air conditioning in response to rising temperatures or switch off lighting upon detecting a gas leak. Moreover, floor pressure sensors and camera devices are utilized for improved monitoring of the elderly, alerting family members in case of emergencies [10], [32].

- **Health and Fitness Monitoring**: IoT technology facilitates continuous health monitoring, benefiting elderly individuals and patients with chronic conditions by enabling a higher degree of autonomy. For instance, wearable devices can monitor vital signs, physical activity, and other health indicators, providing real-time data to users and healthcare providers. This capability allows for the early detection of potential health issues and the implementation of preventive measures [10].
- **Industry and Manufacturing:** detecting potential faults before they occur and optimally scheduling maintenance in a predictive way are the main pillars of this application field. For example, sensors placed on industrial machinery can monitor operating conditions and report faults, reducing downtime and increasing production efficiency [10].
- **Supply chain and Logistics:** IoT devices streamline the process of monitoring goods throughout the supply chain by employing sensors such as RFID and NFC. These sensors aid in the gathering of real-time information on the location and status of products. Subsequently, information systems can analyze this data to predict future demand and obtain valuable insights, thereby enhancing the effectiveness of the complete supply chain network [10].
- **Environment and agriculture:** monitoring systems equipped with sensors measure air quality levels aiding in the reduction of pollution and fostering sustainable practices. In agriculture, precision farming leverages soil and climate sensors to inform specific irrigation and treatment, enhancing crop productivity [10].
- **Smart cars:** using IoT technology, vehicles can now communicate in real-time, both with users and among themselves, as well as with city infrastructure like traffic lights and parking spaces. This network enhances traffic management, predicts congestion, and boosts safety by facilitating the sharing of critical data, thereby streamlining urban mobility [33].
- **Smart Buildings:** this application field concerns the exploitation of the IoT to automate the management of systems inside buildings, using advanced sensors. The purpose is threefold: to improve occupant comfort, optimize energy consumption for greater savings and enhance building security. By analyzing the data collected by the sensors, smart buildings adapt the indoor environment to the users' needs, adjusting temperature, lighting and ventilation efficiently [32].

- **Smart Metering & Grid:** smart meters and smart grids facilitate more efficient energy use, allowing consumers to monitor and manage their energy consumption in real-time. These systems also enable the integration of renewable energy sources, optimizing energy distribution according to demand. This application field is not limited to energy but extends also to thermal, water, and gas resource management [10], [32].
- **Smart Retail:** the enhancement of the shopping experience is achieved by seamlessly integrating the Internet of Things into retail operations, thereby blurring the boundaries between digital and physical shopping environments. For instance, automated checkout systems are implemented to eliminate long queues, while smart mirrors offer interactive fitting experiences. The use of sensors for inventory management ensures precise tracking of stock levels in real time, preventing shelves from being either empty or excessively stocked. Moreover, asset tracking is used to prevent theft and ensure that equipment and products are always in their designated locations. In-store conditions, such as cleanliness and energy usage, are carefully monitored and adjusted via IoT technology to create a superior shopping environment [34].
- **Smart Cities:** The Internet of Things plays a crucial role in Smart Cities, where it is used to monitor and manage various urban aspects, significantly improving the quality of city life. In addition to the regulation of basic services such as public transport, street lighting and parking systems, the IoT extends its scope to the supervision of the urban environment. This includes air quality monitoring, water management and efficient waste collection, with the aim of making cities more livable, sustainable, and competitive. This application field will be further developed in *subsection 1.2.2* where all the application in smart cities will be reviewed [32].

1.1.6. Relationship with Big Data and Artificial Intelligence

Big data refers to large datasets that typical processing methods fail to handle adequately. Smart Cities have used the Internet of Things to improve the efficiency and usefulness of urban areas. As a result of the vast number of sensors used in these surroundings, applications, and online portals, unparalleled amounts of data were generated [35]. The rise in data generation has opened the way for platforms capable of gathering, analyzing, and disseminating information, which is useful in various areas of everyday life [36].

The concept of Big Data is commonly summarized into five primary attributes, famously termed as the 5Vs [37]:

- **Volume:** it refers to the massive amounts of data generated by sensors and people through applications and online portals. In particular, it is estimated that by 2025, there will be 19.08 billion IoT devices in operation, generating 73.1 zettabytes of data [38], [39].
- **Velocity:** it denotes the speed at which data are produced and processed, which can be in real-time or near real-time. It is critical in applications in which a prompt response is needed such as health parameters monitoring or traffic flow optimization.
- **Variety:** Big Data encompasses a wide array of data types, from structured to unstructured, including texts, images, audio, and sensor data.
- **Value:** the value of Big Data lies in the insights it can provide, significantly influencing decisions and strategies. The importance of data is determined by its relevance and the context of its application, whether it is for forecasting, improving services, or understanding patterns.
- **Veracity:** it concerns the reliability of data, and the confidence decision-makers have in it. With Big Data coming from increasingly diverse sources, ensuring its accuracy and integrity becomes a substantial challenge.

In the context of the Big Data paradigm, for the analysis and storage element, numerous technologies including Cloud, Edge, and Fog Computing have been extensively examined in *subsection 1.1.4*. Nevertheless, Artificial Intelligence (AI) plays a crucial role in revolutionizing the analytical procedures of vast datasets acquired from sensors, cameras, and intelligent devices, enabling real-time feasibility [14]. Coming to a definition of AI, the term was introduced by computer scientist John McCarthy in 1979 and it focuses on creating machines capable of performing tasks that typically require human intelligence. In this field, there are various specializations that enable computers to perform complex tasks, ranging from interpreting human language to conducting visual analyses [40]. The main ones, are the following:

- **Machine Learning (ML):** provides software with the ability to improve its performance over time through data analysis, eliminating the need for complex programming. It exploits algorithms to make predictions or decisions based on information acquired from past data [40]. Applications include using information from sensors in industrial machinery to predict malfunctions and analyzing data from wearable gadgets to identify early signs of illnesses, providing personalized healthcare recommendations. Moreover, in intelligent building systems, modifications to heating, cooling, and ventilation according to the number of occupants and prevailing weather conditions can be executed, contributing to a reduction in energy consumption [41].
  This is possible thanks to the main learning modalities categorized as follow [42]:

  - *Supervised Learning:* the algorithm is trained on a labeled dataset, which means it learns from data that already has the answers. The goal is to predict the output for new data based on this training. Techniques include linear regression for continuous data and classification for categorical data.
  - *Unsupervised Learning:* Algorithms in this category work with data without labeled responses. The system tries to learn the patterns and the structure from the data without explicit instructions on what to predict. Methods include clustering, where data is grouped into clusters based on similarity, and dimensionality reduction, which simplifies data without losing key features.
  - *Reinforcement Learning (RL):* these algorithms learn by doing, making decisions, seeing the results, and then adjusting the actions based on rewards or penalties. It is used in scenarios where an agent interacts with an environment to achieve a goal, learning the best actions to take in different states to maximize the reward over time.
- **Natural Language Processing (NLP):** this area focuses on the interaction between computers and human language, with the aim of developing systems capable of understanding and correctly interpreting written or spoken language. NLP is utilized for a range of crucial functions: from chatbots and digital assistants (i.e. Google Assistant, Amazon Alexa) to the analysis of social media content for security monitoring, from gathering public perceptions on urban development initiatives, to providing services in multiple languages [14].
- **Computer Vision**: this field facilitates systems to "see", examining images and videos to extract meaningful information. Computer vision enables computers to recognize objects, scenes, and activities represented in visual input, being applied, for instance, in surveillance systems to detect intrusions.
- **Expert systems**: these are software programs that mimic the judgment and actions of human experts in particular domains. By exploiting rules and data, these systems provide guidance or make decisions in specialized areas requiring expert knowledge [40].
- **Robotics:** it has the scope of developing autonomous machines or robots. These robotic systems are designed to perform tasks, emulate specific human actions, or function in environments where human intervention may be impractical or dangerous [40]. For instance, robots could be used in manufacturing plants reducing the risk of human error and enhancing safety [43].

AI offers several transformative advantages across various sectors, fundamentally changing the way tasks are performed and decisions are made. One of its primary benefits is the dramatic *reduction in human errors*, achieved through data-driven decisions and sophisticated algorithms, leading to enhanced precision in production

plants and in activities such as robotic surgeries. It also introduces a new level of *safety* by performing risky tasks, from defusing bombs to exploring space, where its durable nature and precise functioning outperform human capabilities. This technology ensures *24/7 availability*, outpacing human productivity through chatbots with the ability to handle multiple tasks simultaneously with greater efficiency. Moreover, AI's role in *driving innovation* is evident in fields like self-driving cars where, combined with cameras and sensors, it can improve traffic conditions and safety. Another key advantage is its capacity for *unbiased decision-making*, crucial in fields like urban planning and recruitment. Additionally, Artificial Intelligence excels in performing *repetitive tasks*, significantly improving efficiency in manufacturing processes and allowing humans to focus on creative aspects of their work. It's integration into *daily applications* through apps like Siri, Google Maps and Cortana has made services like navigation and weather forecasting more accessible, enhancing the convenience of everyday tasks [43], [44]. In summary, AI's benefits range from reducing errors and managing risks to enhancing productivity and decision-making. Its ability to automate tasks, provide digital assistance, drive innovation, and improve everyday applications for a safer, more efficient, and innovative future.

1.1.7. Market Parameters

According to forecasts, the worldwide IoT industry is anticipated to be worth around $336 billion in 2024, rising to more than $621 billion by 2030 [45]. Furthermore, the projected rise in the number of IoT-connected devices on a worldwide scale is expected to follow this revenue growth, passing from a current value of 17.08 billion to 29.42 billion by 2030 [39].

The largest markets are China, North America, and Europe, with the first one leading the global market by a significant margin with a revenue of $113.2 billion expected to reach $184 billion by 2030. This figure represents about one-third of the entire global IoT market, highlighting China's pivotal role in the development and deployment of IoT technologies. Concerning North America and Europe they show a revenue value of $72.2 billion and $65.1 billion in 2024 respectively, expected to grow until $38.7 billion and $122.7 billion by 2030 [46]. Focusing on Italy, the revenue will reach $18.95 billion with an annual CAGR of 10.47% until a forecasted value of $28.22 billion in 2028 [47]. This growing trend is clearly linked to the increasing number of smart city applications worldwide. As populations rise and people move into cities, several countries throughout the world are implementing strategies to better manage resources. Sensors, smart meters, and smart lighting techniques are just few examples of internet-connected devices used to improve the efficiency and efficacy of urban infrastructure and services. Furthermore, there is a noteworthy increase in the use of

smart technology in residential and commercial structures placed side by side with the fourth industrial revolution, defined by smart manufacturing practices and the replacement of old infrastructure with intelligent technology [48]. All this is projected to transform the commercial environment and is further powered by the lowered price of sensors and the increasing availability of advanced communication technologies like LoRaWAN, Zigbee, Sigfox, NB-IoT and 5G which enable long-lasting energy consumption duration together with more advanced and real-time applications [49].

1.2. The Smart City

In a fast-changing world, the global population, now estimated at 8.1 billion people [50], is set to undergo an unparalleled demographic transition, with forecasts indicating a rise to 9.7 billion by 2050. This expansion provides new problems and opportunities for the planet's sustainability [51].

The United Nations Department of Economic and Social Affairs, in its latest world urbanization prospect, found that 55% of the world's population is living in urban areas, with projections indicating an increase to 68% by 2050. In 2016, the world had about 512 urban centers with populations over one million and 31 megacities, namely cities with more than ten million residents. Projections suggest that by 2030, the number of urban areas will increase to 662, while megacities will reach 41, with a predominance of these urban giants in developing countries [40]. This wave of urbanization is putting considerable pressure on city governments, which are forced to meet the basic needs of an ever-increasing number of residents. This rapid population growth in cities results in a multitude of challenges, including socio-economic, technical, and organizational problems, putting into a risky position both the environmental and economic sustainability of urban agglomerations [14]. Some major challenges include environmental harm from high pollution levels, traffic congestion, overcrowding, increasing levels of inequality, higher crime rates, health issues, and diseases, large volumes of waste, energy crises needed to keep transport systems, factories, and homes running, among others [52], [53], [54]. The issues arise from the inherent limitation of resources in urban contexts, where the complexity and density of city life make it increasingly difficult to distribute and utilize these resources effectively. This situation necessitates new methods and solutions for managing and distributing the limited resources available, ensuring that they fulfill the expanding needs of urban populations sustainably and fairly.

As stated in the previous *section 1.1*, in recent decades, the widespread diffusion of Information and Communication Technologies has given rise to an era of renewal for commonly used objects, enriching them with "intelligence" to simplify and improve people's daily lives. This technological progress has paved the way for the rise of Smart Cities, conceived as the vision of the urban future, aiming to ensure the well-being and rights of citizens, stimulate a cutting-edge industrial sector, and prioritize urban planning towards sustainability and environmental protection [55]. The adoption of technologies such as the Internet of Things, Artificial Intelligence, and Big Data, to name a few, plays a crucial role in this realm. In the field of smart city research, however, there is a dichotomy between a technocentric and a holistic approach. The former argues that digital innovation should be the focus of smart cities while the latter believes that cities need renewal not only from a technological perspective but also from the perspective of cultural and social regulations and practices, considering the role of citizens and governments of equal importance [56].

1.2.1. Definition and evolution

The evolution of the Smart City concept has roots extending back to the 1980s in the United States, a period when the New Urbanism movement took shape. This current of thought, which emphasized the importance of human-centered urban planning, developed in parallel with the advent and spread of information technology. It was in this context that, during the 1990s, the term "Smart City" made its first appearance in the media, marking the beginning of a new era in urban planning and city management, considering how ICT technologies could be employed to optimize city management [57], [58].

The significant turning point came in 2009 when M.S. Peng, then CEO of IBM, launched the concept of "Smart Earth." This idea, centered on the principles of sensing, connection, and intelligence, aimed to transform the approach to urban management and development by promoting advanced integration of information and communication technology into city infrastructure. The goal was to make cities more responsive and adaptable to the needs of citizens while improving the quality of life, environmental sustainability, public safety, and efficiency of urban services [59].
Until 2010, the literature reported only a few studies regarding smart cities but thanks to the support from Horizon 2020 by the European Commission, a research and innovation funding programme from 2014 to 2020 of around €80 billion [60], the interest and the number of publications significantly heightened.

However, there is no universally accepted definition of a smart city. Indeed, reviewing the literature what emerges is the presence of a multitude of definitions with various interpretations that use terms beyond "smart," such as "digital" and "intelligent." What is clear, certainly, is the centrality of technology, which shows how crucial it is for the

development of projects in this field. Other terms frequently associated with the concept of a smart city are sustainability, efficiency, and quality of life [61].

A particularly persuasive definition of the smart city is proposed by Microsoft, a global pioneer in the technological field, which states: *"Smart city is an urban area that uses an array of digital technologies to enrich residents' lives, improve infrastructure, modernize government services, enhance accessibility, drive sustainability, and accelerate economic development"* [62]. This definition highlights the central aim of a smart city, namely improving the life conditions of citizens. A smart city, according to Microsoft, makes it easier for everyone to move around and access services, helps small businesses grow, and ensures that news and information is readily available to every citizen. It makes government activities more efficient and offers user-friendly community services for all. This type of city works to keep its infrastructure, such as buildings, roads, and bridges, solid and reliable. It is dedicated to protect the environment and improves collaboration between the various sectors of government. It also works to improve public transport, it uses city resources intelligently to avoid waste, and collects and processes data to make urban management and development more effective [52].

Another definition embedding the main elements of the smart city concept is the one provided by Cassandras: *"Smart Cities are: sensible (sensors sense the environment), connectable (networked devices bring the sensed information to the Web), accessible (information on our environment is published and is accessible by users on the Web), ubiquitous (users can access information at any time and in any place, while moving), sociable (users acquiring information can publish it through their social network), sharable (sharing is not limited to data, but also to physical objects that may be used when they are in free status), and visible/augmented (the physical environment is retrofitted and information is seen not only by individuals through mobile devices, but also in physical places such as street signs)"* [63]. This definition introduces sensors and thus IoT as a key enabling technology of the ecosystem, stressing the idea of ubiquity and real-time information to improve the paradigm.

Generally, as defined by Gracias et al., *"Smart cities use digital technologies, communication technologies, and data analytics, to create an efficient and effective service environment that improves urban quality of life and promotes sustainability"* [61]. This last definition provides a comprehensive and concise panoramic of the main pillars of the smart city paradigm, mentioning:

- **Digital Technologies:** IoT, Big Data, AI, and Cloud Computing, technologies discussed deeply in *section 1.1* of this chapter, are just a few of the digital tools that can be incorporated and used in the smart city infrastructure [14]. IoT is the backbone enabling technology, allowing a ubiquitous and connected environment.

- **Communication Technologies:** network communication is crucial for efficient data transmission and real-time monitoring. Devices must talk to each other extremely fast, trying to reduce as much as possible energy consumption. Here the role of innovative technologies such as LoRaWAN, NB-IoT and 5G can be perceived as crucial for positive development in smart city applications.
- **Data Analytics:** the huge amount of data coming from IoT devices such as sensors and actuators needs to be analyzed through algorithms and machine learning techniques, highlighting Big Data, Cloud Computing and AI importance.
- **Efficiency:** integrating digital technologies, data analytics, and communication technologies, it is possible to enhance the services offered by the cities, also enabling quick decision-making by administrators.
- **Urban quality of life and sustainability:** smart city initiatives aim to enhance the overall quality of life for residents by improving access to essential services, promoting civic engagement, and fostering a sense of community. Creating an efficient ecosystem is not sufficient on its own. It is essential to also prioritize sustainability, a key goal of smart cities. This involves using fewer resources, reducing pollution, and safeguarding the environment.

Another key element to consider regarding the concept of the smart city is the fact that its meaning has evolved based on the focus on different themes. For this reason, it is possible to classify smart cities into three distinct categories [57], [58]:

- **Smart City 1.0:** the first version of smart cities focused primarily on technology-driven approaches aimed at enhancing urban development and operational models. This early wave of smart cities was built around the idea of leveraging cutting-edge information technologies to foster intelligent urban planning, construction, management, and services. This approach emphasizes the significant role of technology in facilitating urban development and construction. It is generally agreed in existing theories that during this phase, major technology providers often play a leading role in smart city development.
- **Smart City 2.0:** the second generation of smart cities adopts a more holistic view of urban development. Here, the focus is not solely on technology, but also on how it can concretely improve people's lives. In this vision, governments play a crucial role, not just by implementing advanced technologies but also by ensuring that these technologies solve real urban problems, such as improving public services and making cities more livable. Such a city uses technology not only to be more efficient but also to ensure that development is sustainable, enhancing the lives of its inhabitants today without compromising resources for future generations.

- **Smart City 3.0**: At the heart of this generation of smart cities lies the concept of co-creation. The construction of Smart City 3.0 requires the active participation of urban actors to foster an innovative environment, enhance inclusivity, and engage citizens in the problem-solving process for city development. This shift from being merely passive recipients of services to active co-creators of their life quality is crucial.

1.2.2. Application Fields

A smart city is made up of numerous application fields where technology can be applied to significantly enhance urban living conditions. Eleven key dimensions have been identified, synthesizing recommendations from academic research and insights from the Smart City Observatory at the Polytechnic of Milan. This approach ensures a broad and effective perspective on the subject. Additionally, for each category identified, an example of a real-world project is provided.

1.2.2.1. Smart Mobility

Many cities face traffic challenges, including congestion, pollution, and the need to make public transport more efficient and cost-effective [12], indeed the key idea behind this concept is delivering to citizens high-quality services while at the same time reducing environmental impact [33]. The new concept of Mobility-as-a-Service (MaaS), is revolutionizing this field, implying smart technologies to connect people, governments, and businesses with vehicles, devices, and urban infrastructure. This integration facilitates advanced services for efficient traffic flow, dynamic routing, vehicle sharing, sustainable travel, and safer driving. Predictive models help prevent accidents and manage congestion. Key technologies include sensors, GPS, and communications that enable vehicles to interact with each other and with city infrastructure, enhancing overall urban mobility and safety [13]. Examples of applications in this field are roads equipped with sensors monitoring traffic and road conditions, systems prioritizing safety and movements across the streets adjusting traffic lights and signals according to the pedestrian volume [64], micro-mobility sharing (bikes and scooters), car sharing, green transportation initiatives, automated toll collections carpooling, intelligent traffic lights, integrated transportation services accessible through a unique account with the possibility to pay by the platform. Another example regards the encouragement of multimodal mobility combining different services like bike sharing, public transit, and walking in a single journey putting sharing mobility options near railway, metro, and bus stations. Furthermore,

the significant role of Intelligent Transport Systems (ITS) cannot be overlooked. These advanced systems enhance urban mobility by reducing travel times, lowering fuel emissions, improving safety, and increasing road security. They achieve this by gathering and analyzing, also with the use of optimized AI tools, data from GPS, sensors, cameras, and vehicles. This information is used to keep users informed about traffic incidents, congestion, and weather conditions, and to simultaneously optimize the management of public transport and traffic flow, thereby suggesting more efficient routes [12], [33], [65].

Example of real-world application: Milan, at the end of 2023 embarked on an innovative sustainable mobility project funded by the National Recovery and Resilience Plan (PNRR). The project, called Maas4Italy, focuses on introducing the MaaS model, which integrates various modes of transportation, both public and private, including taxis, car-sharing services, and micro-mobility options like bicycles and scooters, within a single digital platform. This platform is easily accessible through a dedicated mobile app. The primary goal of MaaS is to make travel more flexible, efficient, and environmentally friendly, encouraging less reliance on private cars. This contributes to the development of a more integrated and intelligent urban mobility structure with a reduced environmental impact. Milan has been chosen as the pilot city to test this system together with Rome and Naples, with a total budget of €2.5 million. To participate in the trial, individuals must fill out a form available on the Milan City Council's website and download one or more apps from participating providers: MooneyGo, Urbi, Wetaxi, Aci-Sara Go, and UnipolMove City. Participant citizens receive financial incentives like monthly bonuses to purchase travel packages that can be used across all the platforms involved in the program. An example of collaboration within this project is the partnership between Wetaxi, a smart mobility startup from Turin, and Zity, an electring car sharing service. Users can rent these eco-friendly vehicles and manage payments directly through the Wetaxi app, highlighting a shift towards sustainable and environmentally conscious mobility solutions [66].

Another large area in the Smart Mobility realm is *Smart Parking*, which acts as a subdomain. In recent years, the increase in the number of vehicles on the road has caused not only an increase in fuel consumption and time lost in queues but also an increased need for parking spaces. To address these issues, smart parking solutions have been developed, exploiting technology to make it easier to find and manage parking spaces efficiently. Thanks to advances especially in the Internet of Things, cloud platforms, and AI algorithms, it has been possible to reduce road congestion and increase municipal revenues. Traditionally, parking search was based on manual methods, and it is estimated that 30% of urban traffic is caused by vehicles looking for a parking space, with an average of 8 minutes for each one. In metropolises, this process is particularly time-consuming, fuel-intensive, and environmentally damaging. The smart parking concept rests on three pillars: sensors, communication protocols, and software solutions. Various sensors, such as ultrasonic, infrared, radar, or magnetometers, together with cameras, are essential to monitor the availability of

parking spaces and transmit this information to the central system via networks. Communication protocols, based on wireless IoT technologies, ensure reliable data exchange between sensors and software platforms, which form the core of the smart parking infrastructure. These platforms, thanks to Cloud computing and AI algorithms, process the data received and provide useful services such as real-time occupancy maps, forecasts of future parking availability, and options for online booking and payment of spaces. In addition, advanced smart parking systems can adjust rates according to demand and use video surveillance systems to enforce parking regulations, including the identification of violations. These systems not only store valuable data but are also crucial tools for improving the quality of urban life and city mobility. The user-facing aspect of these technologies, known as e-parking, makes information easily accessible via smartphone applications or web browsers, thus simplifying parking search, reservation, and payment and improving the overall driver experience [33], [65], [67].

Example of real-world application: The Meliana City Council, a city located in Spain near Valencia, in 2022 set up a network of smart parking lots around "Plaza de la Libertad" with the goal of improving traffic management, reducing noise, and cutting down on environmental pollution. The plan involved installing sensors in 50 parking spots, each equipped with individual sensors, and placing warning signs at the entrances of the town to direct drivers to available parking. The technology used included smart parking sensors that work on magnetic technology and are placed on the road surface so that vehicles can park directly over them. These sensors provide real-time data on parking space availability and work together with electronic signs at the city entrances and a mobile app that notifies drivers when parking spots are free. This system not only makes parking easier for residents and visitors but also helps create a more sustainable urban environment by reducing the number of vehicles driving around looking for parking [68].

1.2.2.2. Smart Lighting

In the urban environment, street lighting is not only a crucial infrastructural element for the safety of pedestrians and motorists but also accounts for a significant portion of overall energy consumption, accounting for approximately 13-14% of annual electricity production. With the number of streetlights projected to grow to around 363 million by 2027, it is imperative to direct attention to efficient strategies to mitigate the energy consumption of these lighting systems. At the heart of this transformation is the choice of light sources. LED lamps emerge as the most efficient solution compared to previous technologies such as High-Pressure Sodium (HPS) or Metal Halide (MH) lamps. Due to their long life, which can range between 50,000 and 100,000 hours (against 12,000 to 24,000 of HPS), and their higher energy efficiency, LED lamps significantly reduce maintenance costs, energy consumption, and consequently the

level of CO2 emissions. A significant advance in this area is the introduction of lighting control networks which present themselves as a substantial improvement in the direction of more intelligent and sustainable street lighting. These networks enable remote control and dynamic and adaptive lighting management, adjusting light intensity according to traffic conditions and actual environmental and time-of-day needs, thus contributing to reduced energy consumption, minimized operating costs, and increased road safety [69].

Example of real-world application: in 2022, the city of Düsseldorf launched a project to modernize its public lighting system. By implementing high-efficiency LED technology, the city aims to reduce energy consumption and environmental impact. The project, managed by Stadtwerke Düsseldorf, uses the Interact Connected Lighting system from Signify and in the pilot phase it included 42 Philips LumiStreet lamps installed along a busy city center street. These lamps are networked and can be individually controlled through a dashboard, allowing for dynamic lighting adjustments based on real-time traffic and pedestrian data. This capability helps reducing unnecessary light, cutting down on CO2 emissions and energy use, with a proven energy savings of 60% during the pilot phase. The system not only enhances energy efficiency but also supports emergency services by instantly increasing lighting levels when needed. Additionally, it simplifies maintenance with lamps that send real-time status updates to the city's dashboard, allowing for detailed energy usage monitoring and swift maintenance actions. After the pilot, from 2022 to 2024, more than 3,000 public light have been installed and looking ahead, Düsseldorf plans to expand this smart lighting network to include over 50,000 public lamps, transforming the lighting infrastructure not just into a source of light but a platform for further smart city innovations [70].

1.2.2.3. Smart Waste Management

According to World Bank estimates, global waste generation reached 2.01 billion tons in 2016, with projections indicating an increase to 3.4 billion tons by 2050 [71]. Given this growing amount of waste, the adoption of smart waste management strategies becomes crucial in the context of smart cities, signaling a growing interest in sustainable urban development initiatives worldwide. IoT technologies and advanced data analytics are transforming the waste management sector, introducing more efficient and environmentally friendly methods. The use of advanced sensors in waste bins (smart bins), provides accurate fill level information in real-time through IoT wireless technologies, optimizing collection, route planning through AI, and significantly reducing operational costs and fuel consumption. These innovations also help prevent the overloading of bins and the omission of collections, thus ensuring greater urban cleanliness. In addition to sensors, RFID technology is widely used to improve the traceability of bins, ensuring that they are not lost and making the collection service more effective. The detailed analysis of the collected data also makes

it possible to map specific waste disposal habits in different areas, enabling targeted adaptation of services and promoting greater citizen responsibilities towards waste management [72], [73], [74].

Example of real-world application: in 2023, Madrid undertook the implementation of a smart waste monitoring system created by Sensoneo, marking the largest smart waste management project in Europe. The project involves the installation of over 11,000 sensors in various types of containers (for lightweight packaging, textiles, glass, organics, and general waste) integrated with an advanced cloud-based management software system. These sensors, which are resistant to water and impacts, employ technologies such as NB-IoT, Sigfox, LoRaWAN and GPRS to transmit real-time data on the fill levels of containers, thereby enabling more efficient waste collection. This data helps in the optimal planning of collection routes, reducing traffic, emissions, and operational costs. Moreover, a dedicated app, available for Android and iOS, allows citizens to identify the nearest bins and interact with the service for warning or maintenance requests. This system not only increases the efficiency of waste collection services but also significantly reduces the urban environmental impact [75], [76].

1.2.2.4. Smart Environmental Monitoring

Climate change is the most significant obstacle to global health today. Climate impacts are already negatively affecting human well-being, causing problems such as air and water contamination, diseases, and intense natural disasters [77]. Therefore a fundamental pillar of Smart Cities is the use of advanced technologies for continuous monitoring of the environment, including air and water quality, as well as the prevention of natural disasters such as landslides and floods, which is crucial [8].
IoT-based systems play a key role in detecting environmental parameters, including levels of harmful pollutants in the air, such as carbon dioxide (CO2) and nitrogen oxides (NOx), which pose a significant threat to public health and actively contribute to climate change. These advanced sensor devices also measure critical water quality parameters such as pH, turbidity, and total dissolved solids, as well as monitor environmental variables such as temperature and humidity [13]. Noise pollution is also part of the measurements taken, underlining the breadth of assessments required for a healthy urban environment.
Collecting and analyzing this data allows municipalities to be constantly informed about the conditions of the environment and promptly intervene with corrective measures if the measured levels exceed safe thresholds, promoting environmental sustainability initiatives [16]. In addition to pollution management, sensor technology also plays a key role in the prevention of catastrophic events. By monitoring river levels and assessing the risk of landslides, proactive strategies can be implemented to mitigate the impact of potential natural disasters [73].

Example of real-world application: *Ingapres, an engineering company specialized in wastewater treatment operating in Barcelona, in 2023, has adopted smart environmental monitoring equipment produced by a qualified provider called Oizom to address issues related to the presence of hydrogen sulfide (H2S) in sludge treatment processes. H2S, a toxic gas produced by anaerobic decomposition of sludge, poses significant health and environmental risks, including irritation to eyes and respiratory systems and potential damage to the central nervous system. The solutions provided by Oizom feature advanced sensors that not only detect H2S levels but also, through the integration of automation relays, automatically activate intervention systems when gas levels exceed established safety thresholds. This automated detection and response system ensures proactive management of the environmental and health risks associated with wastewater treatment. Additionally, Oizom's equipment easily integrates with third-party platforms, allowing reliable and high-quality data management through their environmental software. This approach to smart environmental monitoring not only enhances safety but also contributes to the sustainability of wastewater treatment operations* [78].

1.2.2.5. Smart Agriculture

This type of application field makes particular use of advanced sensors in both plants and agricultural soils, allowing data on various environmental factors to be collected and analyzed. This innovative approach facilitates the optimal management of resources, such as the accurate control of soil humidity and atmospheric conditions, to optimize crop production and minimize the risks of diseases and pests. Through the targeted regulation of moisture and temperature, problems such as the development of harmful fungi can be effectively prevented. Furthermore, the ability to predict adverse weather events such as excessive rainfall, frost, or periods of drought enables farmers to take preventive measures, thus ensuring sustainable, high-quality agricultural production [2], [8], [12].

Example of real-world application: *AgriDataValue is a project started in 2023 funded by the EU through Horizon Europe, which aims to transform agriculture through an advanced platform that integrates data from IoT sensors, drones, and satellites to address industry challenges. The platform analyzes real-time data to optimize the use of resources like water and fertilizers, prevent diseases, and manage crops and livestock more effectively. It will be tested on over 181,000 hectares with the help of 4,200 farmers, using technologies like automated irrigation, disease monitoring with drones and multispectral images, and autonomous irrigation area management systems. These innovations aim to improve the quality of agricultural production and the sustainability of farming practices. The project, valued at about €7 million, involves countries including Italy, Spain, England, Latvia, Lithuania, Poland, Germany, France, and Greece* [79], [80].

1.2.2.6. Smart Building

This field of application marks a transformative shift in living and working environments, promoting spaces that are both energy-efficient and environmentally sustainable. These buildings are characterized by their ability to automatically adapt to the needs of their occupants, adjusting temperature, lighting, and ventilation through the use of advanced sensors. These sensors detect changes in the indoor and outdoor environment, allowing the system to optimize conditions without wasting energy. By centralizing the control of all systems, from lighting to heating, smart buildings can prevent problems before they occur, improving their efficiency and reducing the risk of failure. This not only ensures smoother operation but also helps to extend the life of the building itself. The key aspect of smart buildings is their commitment to energy efficiency. As traditional buildings are among the largest consumers of energy, the adoption of technologies that minimize consumption and reduce environmental impact is crucial. Heating, ventilation, lighting, and energy metering systems are designed to use resources intelligently, contributing significantly to the reduction of harmful emissions. Also, the role of data analysis and machine learning techniques is central in this field since it gives the possibility to extract insights about the functioning patterns of building and consequently make wise management decisions [81]. Within the category of intelligent buildings, another particularly relevant functionality is the monitoring of the structural state of the infrastructure. This feature allows the condition of supporting structures and building elements to be continuously observed and analyzed to identify any signs of deterioration or damage at an early stage. Through the use of advanced sensors, parameters such as vibrations, and changes in temperature and humidity, the integrity of buildings can be monitored in real-time. The aim is to intervene promptly with maintenance or repair actions before small problems become serious and costly to fix. This not only ensures the safety of those living or working inside the building but also extends the life of the structure, maximizing the initial investment [12].

Example of real-world application: Zenner, a German company specializing in innovative measurement technologies and IoT solutions for smart cities, has introduced a new technology called "Zenner Building Link". This system allows for the control of smart radiator thermostats in buildings, facilitating optimized energy management. Using LoRaWAN technology, it supports long-distance, low-energy communication and easy retrofit installations in existing buildings without structural modifications. The ability to remotely adjust the heating of entire buildings based on actual usage through a software platform can reduce energy consumption by up to 31.5%. An additional feature of the system is its capability to promptly report thermostat malfunctions, enabling predictive corrective actions. In 2023, over 500 thermostats were installed in the Administrative Building of the City Bank in Frankfurt, Germany [82].

1.2.2.7. Smart Metering & Grid

The adoption of advanced metering systems is revolutionizing the energy, gas, and water sectors, introducing more efficient and sustainable methodologies for monitoring, and managing resources. These systems exploit new-generation meters for precise control of energy consumption and careful management of water and gas resources. In the energy field, these devices make it possible to analyze and optimize energy use, facilitating a detailed consumption balance. In parallel, in the water sector, the focus is on minimizing dispersion along distribution networks, thus aiming to reduce waste and increase operational efficiency [73]. In conventional electrical systems, energy is generated by large plants, such as hydroelectric or thermoelectric ones, and then transmitted through a network that brings it directly to homes and businesses. This process creates a flow of energy that moves in one direction, from the generating plant to the end consumer. Within this system, there are crucial facilities known as substations, strategically placed near the consumers. These substations function as control points along the electricity grid, with the task of monitoring the amount of energy flowing through them. By collecting data on energy consumption, the substations send this information back to the generating stations, allowing them to adjust energy production according to overall demand. However, the system has one significant limitation: it is inherently one-way in terms of communication. Although power plants can receive aggregated information on energy consumption, there is no direct connection with individual consumers. In other words, there is no mechanism for power plants to know and regulate energy production based on the actual and instantaneous consumption of each consumer, such as a specific household or business. This one-way system limits the ability to optimize energy efficiency and adapt energy production to specific and immediate fluctuations in demand. To solve the mentioned problem, the implementation of the latest generation of electricity grids, called smart grids, is increasingly being proposed in the smart city paradigm, revolutionizing electricity distribution and consumption patterns. Leveraging advanced technologies such as sensors and AI, smart grids ensure efficient energy allocation through real-time monitoring. This not only promotes more conscious energy consumption but also significantly reduces waste [12]. These advanced energy systems are also able to effectively integrate renewable and eco-friendly sources, like photovoltaic panels and wind-turbines, in a widespread manner, aiming to distribute them efficiently to reduce energy consumption. Citizens, businesses, and public authorities, in Renewable Energy Communities, work together to produce and exchange clean energy, highlighting a shift towards more sustainable and participatory ways of managing energy resources [13]. These innovative approaches not only highlight the potential of smart technologies in optimizing the use of natural resources but also signal a growing awareness towards more sustainable and responsible practices that are crucial in addressing the environmental challenges of our time.

Example of real-world application: *"Smart Grids Valle d'Aosta", managed by Deval, a company in charge of the distribution of electric energy, is a project funded with €18.2 million from the Italian NRRP, aiming to improve the energy infrastructure in the region involving 69 municipalities. The main goal is to support the electrification of consumption and increase the network's capacity to handle energy from renewable sources. To achieve this, Deval plans to replace medium-voltage transformers and install a new electrical line of 16 km to boost the network capacity up to 102 MW. Another aspect of the project is replacing 90 transformers to enhance the low-voltage power distribution, thus facilitating domestic electricity use and electric mobility. Additionally, the project includes adopting advanced technologies such as remote-controlled switches, sensors, smart meters and a distribution management system software, allowing for more effective monitoring and control of energy consumption. These innovations help better manage the network and respond quickly to any malfunctions. Started in 2023 and scheduled to be completed by June 2026, this project not only improves energy efficiency but also helps reduce CO2 emissions, supporting environmental protection and promoting a transition to cleaner, more sustainable energy use* [83].

1.2.2.8. eHealth

Technology significantly enhances healthcare delivery and efficiency. IoT technologies are central to this transformation, enabling a sophisticated network where patients, healthcare personnel, and crucial assets such as emergency vehicles, blood supplies, and organs for transplantation are continuously monitored and managed. This comprehensive tracking system ensures that resources are optimally allocated and that patients receive timely care, thereby improving overall service quality.

The use of specialized databases for patient identification markedly reduces medical errors. By precisely identifying patients, healthcare providers can administer correct medications and dosages, enhancing patient safety. Similarly, staff authentication mechanisms ensure that only authorized personnel can access sensitive areas and patient information, maintaining high standards of care and privacy.

Automated data collection and analysis through sensory devices measuring vital parameters (heart rate, blood pressure, oxygen saturation, body temperature, respiratory rate) streamline information processing, minimizing the reliance on manual entry and the associated human errors. These devices, capable of capturing biometric and physiological data in real-time, facilitate the continuous monitoring of patients' health, supporting more accurate diagnoses and enabling personalized treatment plans, tailoring healthcare to individual patient needs [16]. It is possible to monitor patients also in remote mode through these wearable sensors enabling better management of chronic diseases and continuous monitoring of health conditions without the need for the patient to be physically present in a healthcare facility. This approach represents a step forward in healthcare since it allows managing effectively

patients in the comfort of their own homes while reducing the overload of healthcare facilities [13].

Example of real-world application: in 2022, Chronolife, a healthcare services company, initiated a clinical investigation in partnership with Rigshospitalet in Copenhagen, a well-known hospital in Denmark. The primary goal of the research was to examine the potential benefits of remote patient monitoring in enhancing cancer care, with a focus on continuous and efficient assistance. Chronolife created Keesense, a smart t-shirt serving as a medical tool for continuos monitoring of various physiological parameters, specifically for the study. This innovation enabled healthcare providers to supervise patients' well-being from distance with precision, thereby decreasing the necessity for frequent hospital trips. Throughout the three-week examination, both young adults and elderly individuals undergoing cancer treatment wore Keesense for 12 hours daily, while a smartphone application gathered and evaluated the transmitted physiological information. The investigation sought to evaluate patients' comfort and acceptance of Keesense, assessing its efficacy in facilitating a normal lifestyle and enhancing their emotional well-being during therapy. Keesense was developed to grant patients more autonomy, lessening sensations of loneliness and fostering optimism, which are vital elements in coping with the emotional hurdles of the illness. Upon completion of the study, Chronolife and Rigshospitalet collaborated on drafting scientific papers detailing the results, offering valuable insights into oncology and remote monitoring to shape future cancer care strategies, thereby improving early intervention and tailoring care further for patients. [84].

1.2.2.9. Smart Security

Residents believe that safety is a crucial aspect of modern cities. Ensuring it requires regular surveillance of every aspect of the city, however analyzing the collected data and spotting illegal actions is difficult. Innovative techniques for improving security in smart cities have lately been presented. Unlike classic surveillance systems, which simply capture images without intelligence processing and are subject to human control, modern technologies allow for proactive monitoring of human actions. These technologies, thanks to artificial intelligence algorithms, can not only recognize violent acts and the persons involved, but they can also send out automatic notifications in reaction to anomalous events. Furthermore, they help with urban planning by monitoring pedestrian movements and evaluating traffic patterns. This is especially crucial in settings with high-density places, such as concerts or airports, to efficiently control crowds and respond quickly in emergency circumstances. Thermal cameras are an interesting tool increasingly used in nighttime surveillance by sensing temperature differences. Another key characteristic is their capacity to detect forbidden or harmful objects carried by persons, by carefully analyzing their silhouettes and any anomalies through AI advanced algorithms [16].

Example of real-world application: Nokia Drone Networks, together with Citymesh, a telecommunications operator based in Belgium, proposed a groundbreaking solution in 2023 that leverages advanced technologies for enhancing public security. This pioneering initiative unveiled the world's first national drone network in Belgium, utilizing 70 Drone-in-a-Box (DiaB) units to establish a fully automated 5G drone network. The drones are strategically positioned across 35 emergency zones in the country and are designed to be activated instantly, ensuring continuous coverage round the clock. Each drone is equipped with sophisticated video and thermal cameras, capable of capturing high-definition thermal images. These images are further analyzed by artificial intelligence to detect crucial elements like smoke plumes, specific fire parameters, and the presence of individuals nearby. Real-time data collection plays a vital role in this system, providing emergency services with valuable insights within the critical first 15 minutes after an incident occurs. The high speed and efficiency of data gathering and transmission facilitated by 5G technology enable emergency teams to be well-prepared and informed before reaching the incident site [85], [86].

1.2.2.10. Smart Tourism

The concept is based on the strategic use of digital technologies to improve the visitor experience and the efficiency of tourism-related services. Through the in-depth analysis of real-time collected data, both numerical and descriptive, tourist movements can be managed more effectively, and greater safety can be ensured in cities. The main objective is to facilitate access to various services for travelers and people living in urban areas, using applications and digital platforms that make navigating around cities and interacting with their cultural and social offerings more intuitive [73]. In this context, IoT devices, mobile applications, services based on geolocalization, virtual and augmented reality, and social media, play a key role. These technologies make it possible to provide tourists with real-time and personalized information, significantly enhancing their travel experience. For instance, they can help visitors discover hidden attractions, avoid queues, get tips on local events or cultural experiences, and easily navigate unknown areas [13].

Example of real-world application: "Orvieto nel metaverso" is an innovative project developed by Engineering, a software company, in partnership with the Municipality of Orvieto, unveiled at the TTG fair in Rimini in 2022. This project allows users to virtually visit Orvieto, providing an interactive and engaging digital experience through AR. In this virtual environment, visitors can interact with public services, enjoy the city's cultural and artistic works, participate in virtual exhibitions, and shop in 3D, along with accessing various informational content. A virtual guide, the avatar Anna who is Orvieto's mascotte, leads visitors through the digital journey which starts with an aerial view of Orvieto, zooming in to land at Piazza Duomo. From there, users can navigate through different virtual rooms interact with exhibits, explore virtual museums, learn about local products, and virtually visit the city's main tourist

attractions. A unique feature of the project is the option for users to obtain an Orvieto Municipality ID card in the form of an NFT (Non-Fungible Token), which turns them into virtual citizens of Orvieto through an interactive game included in the tour. The project is a collaboration between Engineering's Metaverse Lab and Municipia, supporting the digital transformation of over 1,000 Italian municipalities. While the virtual experience is designed to complement, not replace, a physical visit, it aims to enhance Orvieto's appeal by overcoming physical barriers and making the city accessible to everyone. Plans are in place to expand the project by incorporating more partners and services, aiming to make the experience even more comprehensive and immersive [87].

1.2.2.11. Smart Governance

Urban administrations are constantly seeking strategies to make successful, timely, and solid decisions. To achieve this objective, the role of the enormous amount of data generated by smart cities in its various applications is crucial, as valuable insights can be gained from this. Through dynamic dashboards, namely tools that visualize and analyze data in real-time, it is possible to tangibly improve decision-making and plan projects in a more aware way [36]. It is the clear example of the digital twins of cities that provide a comprehensive overview of the state of the city rather than online platforms that facilitate collaboration and co-creation with citizens, companies, and other administrative entities. Citizens can even be used as sensors through the collection of data from their mobile devices resulting in mobile crowdsourcing [13]. Indeed, governments administering smart cities are developing and offering a wide range of digitally accessible public services via the Internet. This approach aims to make it easier and more immediate for citizens to interact with administrations and access high-quality services directly from their electronic devices, such as smartphones or computers, improving the quality of urban life and their overall experience [36]. In this category, we include, among others, projects ranging from the development of platforms and applications that allow access to city-related data to the implementation of public 5G networks, Wi-Fi areas, mobile device charging stations, and digital information panels. It is crucial to ensure that citizens are actively involved in urban planning and decision-making processes. This is achieved by encouraging active participation from residents through interactive platforms and feedback mechanisms, allowing them to express opinions and suggestions. The aim is to create an urban environment that effectively meets the needs of its inhabitants, improving the quality of life through the smart use of digital technologies. In this way best practices can be shared across the broad smart city ecosystem so that other cities can replicate such models resulting in a continuous innovation of the urban landscape [64].
Example of real-world application: in 2023 the project "Bologna Digital Twin" was presented at the "Rebuild" event of Riva del Garda, aimed at providing the city with an advanced digital

infrastructure that integrates and analyzes data from multiple sources such as IoT sensors, GIS systems, real estate and urban registries, along with direct input from citizens. Using machine learning algorithms and artificial intelligence, the system processes this data in real time, supporting the city administration in simulating decision-making scenarios and assessing impacts before implementation. This technology enhances effective management of emergencies by improving responses to events like floods or natural disasters. Additionally, it helps in optimizing urban mobility and energy efficiency, suggesting solutions to reduce traffic congestion and promote renewable energy use. Finally, the digital twin encourages greater citizen participation by enabling residents to actively engage with urban policies through a platform that facilitates feedback and idea submission. The project, evaluated €7 million, is financed by the European Union through the European Regional Development Fund.

1.2.3. Benefits and Challenges

In the context of urban transformation, the emergence of smart cities marks a qualitative leap toward a more interconnected and technologically advanced future. These urban ecosystems integrate technological innovation to better meet the needs of their inhabitants and their environment. However, the path toward the realization of these smart cities is strewn with significant challenges that require careful attention.

Starting from the benefits, the main ones, as defined by Gracias et al., are the following [61]:

- **Improved quality of life:** the use of advanced technological solutions in smart cities is aimed at simplifying the daily lives of inhabitants. For example, the introduction of advanced mobility systems can minimize traffic congestion and waiting times, and surveillance systems can improve public safety. These innovations translate into an increase in overall well-being, making urban environments more desirable for residents and investors.
- **Stimulated economic growth:** digital transformation and the adoption of new technologies in urban services can attract innovative companies and start-ups, generating a positive spiral of economic development. Smart Cities act as incubators of innovation, attracting capital and talent and promoting a vibrant business environment. This fosters job creation and boosts the local economy.
- **Promoting sustainability:** ecological efforts, such as the adoption of clean energy sources and the reduction of carbon emissions using environmentally friendly means of transport, are the pillars of smart cities. These actions not only elevate the quality of air and the urban environment but also contribute to the battle against global warming, increasing the resilience and sustainability of cities over time.

- **Operational efficiency:** automation and digitization of municipal services, ranging from waste management to energy supply, enable more efficient management of resources and less waste. These processes lead to a significant improvement in urban operational efficiency, with benefits in terms of time and cost savings.
- **Enhanced governance:** through the collection and analysis of data, municipalities can optimize the management of urban services, responding more effectively and purposefully to citizens' needs. This approach allows them to improve the efficiency of services, predict and prevent future problems, and plan strategically for the long term.

Naturally, the extensive use of technology in developing smart city projects brings with it several significant challenges. These challenges must be carefully considered and addressed during the planning and implementation phases to ensure the success of such initiatives. Below, the most important ones are highlighted:

- **High implementation costs**: the introduction of new technologies and infrastructures requires significant financial investments and long lead times for planning and implementation. This process involves expenditures for purchasing advanced technological equipment, upgrading existing systems, and training personnel. Moreover, the integration of these technologies into the urban fabric may reveal additional investment needs in security and data management, further increasing overall costs [61].
- **Privacy and security issues:** related to poor protection and confidentiality of personal data, which discourages people from providing information and interacting with technologies that require their active participation. The large amount of data acquired by sensors and saved in the cloud also raises the possibility of cyber-attacks, which could compromise the entire smart city infrastructure. A significant example of such a danger was the 2015 cyberattack on Ukraine's power infrastructure, which left 225,000 people without energy [12].
- **Adoption:** the inclination of citizens towards digital innovation is essential to transform a city into a smart environment. If inhabitants are reticent or indifferent to new digital technologies, the goal of creating a true Smart City becomes unachievable. For a Smart City project to be successful, citizens must be willing to actively adopt these changes, taking advantage of the services offered to improve their quality of life [33].
- **Environmental threats:** dealing with emergencies caused by catastrophic natural events is a crucial challenge for smart cities. Disasters such as flooding, earthquakes, and landslides can seriously compromise basic infrastructure, negatively impacting the efficiency of the smart urban ecosystem [33].

- **Heterogeneity of devices and data:** a smart city involves the use of many different technologies and therefore there is a tangible risk that these are not compatible with each other [61]. This problem arises because these devices use different programming languages, operating systems that generate different types of data, different communication protocols and standards [33], [88].
- **Data quantity and quality:** dealing with the massive amount of data generated by the numerous connected devices operating in real-time is another significant challenge, as it is not only a matter of managing massive volumes of data that must be analyzed promptly to extract valuable information, but also of ensuring the quality of this data, which is often incomplete or inaccurate. To improve efficiency, it is therefore crucial not only to collect and process large amounts of data but also to ensure that these are correct and reliable, thus avoiding basing decisions on incorrect information [88].

All these difficulties faced in the smart city realm are interconnected and have a close connection with data management. Corsi et al. provided an interesting analysis of how these challenges are interrelated, as illustrated in *Figure 4*.

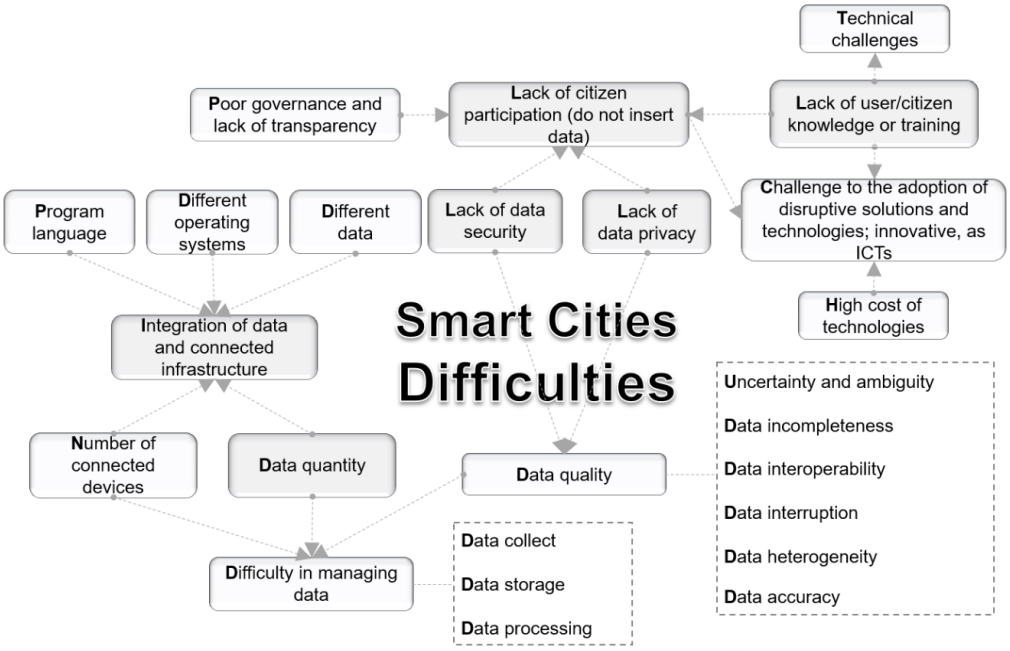


Figure 4: Smart Cities difficulties (Corsi et al., 2022)

1.2.4. Relationship with Sustainable Development Goals

On September 25th , 2015, 193 members of the United Nations adopted a global agreement known as the 2030 Agenda for Sustainable Development, marking a collective commitment to sustainable progress, reaffirming the importance of sustainable economic growth, social inclusion, and environmental protection, all promoted in a context of international peace and collaboration [89].
As can be seen in *Figure 5*, the 2030 Agenda is distinguished by 17 global objectives, which represent an ambitious plan of action in a variety of sectors, including education, gender equality, sustainable resource management, and climate change mitigation. This agenda not only promotes inclusive and sustainable economic growth but also stimulates the global acceptance and dissemination of sustainable technology, a critical step toward a greener and more equitable future for all [88].

Figure 5: 17 Sustainable Development Goals (United Nations)

The 2030 Agenda for Sustainable Development is based on five key areas that guide global action towards a better future for all [89]:

- **People:** from SDG 1 to 5 the aim is to completely abolish poverty and hunger, aspiring to ensure decent and equitable living conditions for all, in a healthy environment.
- **Environment:** SDGs 6, 12, 13, 14, and 15 are dedicated to the protection of the environment and the battle against climate change, aiming to preserve the health of the planet for present and future generations. This translates into

initiatives for responsible consumption and production and the care of natural resources.

- **Prosperity:** from SDG 7 to 11, the agenda aims at ensuring prosperity for all by promoting environmentally friendly economic, social, and technological development.
- **Peace:** Goal 16 focuses on the importance of building societies based on peace, justice, and inclusion, supported by strong and credible institutions.
- **Collaboration:** with SDG 17, the emphasis is on the crucial importance of solid global cooperation based on solidarity and attention to the needs of those most at risk.

In essence, the 2030 Agenda commits to a future where the principles of universality, inclusiveness, interconnectedness, indivisibility, and cooperation are central, with the ambitious goal of excluding no one from the path to inclusive and sustainable progress [89].

Through the introduction of the SDGs, the concept of "Sustainable City" was introduced, bringing the concept of Smart City to a broader concept summarized in "Smart Sustainable City". This model combines the goals of sustainable development and technology to foster more efficient urban services and infrastructure, improve citizens' quality of life, and bring economic and environmental benefits, helping to make cities and services more sustainable. Such urban environments make intensive use of information and communication technologies (ICTs) and the Internet of Things (IoT) to collect, analyze, and process data from various city domains. This enables the development of smarter functions and services and provides useful information for strategic decision-making related to sustainability [88].
In light of this, there are several SDGs that are more relevant than others in the smart city context being more frequently impacted, among these we find:

- **SDG3 (Good Health and Well-Being):** *"Ensure healthy lives and promote well-being for all at all ages"* [90]. The concept of Smart City plays an important role in improving health and well-being within urban environments, addressing a variety of issues that compromise public health, such as physical inactivity, poor water quality, pollution, high population density, and a lack of food security. Adopting smart city solutions can provide numerous benefits, including reduced emissions through the use of electric vehicles and renewable energy sources, improved air and water quality through the use of artificial intelligence for health analysis, improved waste management, and increased accessibility to services [91].
- **SDG 6 (Clean Water and Sanitation):** *"Ensure availability and sustainable management of water and sanitation for all"* [90]. Smart cities have significant advantages for optimizing water management by exploiting smart metering and smart grids. The application of IoT and AI technologies makes it possible

to fine-tune water distribution and closely monitor any leaks, thus helping to reduce waste [91].

- **SDG 7 (Affordable and Clean Energy): "***Ensure access to affordable, reliable, sustainable and modern energy for all"* [90]. Energy production, transportation, distribution, storage, usage, and self-consumption are all included in energy management [89]. The encouragement of the adoption of renewable energy sources, the precise tracking of consumption through smart metering, and the development of smart grids for the efficient distribution of energy represent the most significant initiatives [91].
- **SDG 8 (Decent Work and Economic Growth):** *"Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work"* [90]. The spread of COVID-19 and subsequent geopolitical and international tensions have had a significant effect on the global economy, damaging employment, international innovation, and logistics. As a result of these challenges, the most developed nations are valuing new economic paradigms, such as the Circular Economy (CE), and are working to promote environmentally conscious progress. CE emphasizes the use of innovative technologies to improve resource management, support the development of policies based on concrete data, modernize existing infrastructure, and introduce new financial mechanisms [91]. As previously stated in the benefits and challenges section, the adoption of these models can result in startups and innovative enterprises attraction, which contribute to the creation of jobs and the advancement of innovation.
- **SDG 9 (Industry, Innovation and Infrastructure):** "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"* [90]. Smart cities promote the emergence and development of diverse technologies by acting as centers of innovation. This means for example using advanced technologies to improve services such as transport, waste management, and make buildings and infrastructures more durable [89], [91].
- **SDG 11 (Sustainable Cities and Communities):** *"Make cities and human settlements inclusive, safe, resilient and sustainable"* [90]**.** Sustainable Development Goal 11 represents the most obvious link between the 2030 Agenda and urban areas, placing a direct focus on cities. It encompasses a series of targets that outline its main areas of focus, starting with the need to ensure safe and affordable housing and ending with the promotion of sustainable transport systems that improve mobility within urban ecosystems. In this context, the adoption of systems for the structural monitoring of buildings becomes vital, as does the implementation of sharing solutions and the use of electric public transport. Special attention is paid to the preservation of cultural and natural heritage and the importance of mitigating the environmental impact of urban centers. These goals can be achieved, for example, through the constant

monitoring of air pollution, the introduction of renewable energy sources, the creation of green spaces, and the adoption of measures to reduce vehicle traffic. SDG 11 emphasizes the importance of robust national and regional development planning based on policies to minimize waste and actively involve citizens, laying the foundation for prosperous and resilient communities. To summarize, SDG 11 acts as a convergence point for numerous other SDGs, adapting various principles to the specific urban context [89], [91].

- **SDG 12 (Responsible Consumption and Production):** *"Ensure sustainable consumption and production patterns"* [90]**.** The objective in this context is to reduce the ecological consequences of urban activities through the endorsement of consumption and production methods that are harmonious with the environment. A practical example can be found in smart waste management practices or smart grids enabling more agile and precise energy, water, and gas management, contributing to a more rational use of the involved resource and a reduction in waste [89].
- **SDG 13 (Climate Action):** *"Ensure sustainable consumption and production patterns"* [90]. Cities play a key role in the fight against climate change, being major emitters of greenhouse gases. The adoption of advanced technologies such as Artificial Intelligence and IoT is crucial to optimize resource management, reduce energy consumption and emissions, and promote sustainable practices. These tools also offer innovative solutions to improve efficiency in waste collection and integrate renewable energy, thus supporting several SDGs [91].
- **SDG 17 (Partnership for the Goals):** *"Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development"* [90]. This means emphasizing the importance of alliances involving various actors such as citizens, government entities and companies to foster the exchange of data and technological practices. An example of how this can be achieved is the creation of open data platforms to foster knowledge exchange and speed up the innovation process.

From the detailed analysis of the goals set by the 2030 Agenda, the interconnection between them and the way in which a single intervention within the context of smart cities can influence more than one becomes evident, highlighting the crucial importance of the smart city concept in contributing to the realization of more prosperous, sustainable, and environmentally friendly cities. This approach not only benefits the well-being of citizens but also promotes economic growth and the adoption of innovations, demonstrating that it is possible to move towards sustainable development without having to sacrifice economics or the introduction of new technologies.

1.2.5. Funding Scheme

Smart City projects require extensive financial resources to be implemented and the ways in which money is raised are among the most diverse. A first differentiation to keep in mind is the one between "financing" and "funding". The word “financing” refers to debt and equity instruments while on the contrary, “funding”, refers to entities, usually of public nature, that make money available for the achievement of results that can benefit the entire community. In this case the typical example is represented by European Union programmes [92].

Going into the specifics of the “financing” modalities, the following modalities are mainly defined:

- **Debt**: in this situation, an entity, whether public or private, borrows money from a bank, investors, or a financial institution. The loan has a maturity date, which specifies when the principal and interests that have accumulated must be repaid. In particular, interest rates might be fixed or variable, and repayment of the amount received can be postponed until the financed project begins to generate positive cash flows [92]. Examples in the European setting include the *European Investment Bank (EIB)* and the *European Bank for Reconstruction and Development (ERBD)*. EIB is an autonomous agency that offers advantageous loans for projects aimed at achieving European Union objectives and it is able to lend more than 25 million euro directly, aiming to support economic growth, employment and projects to fight climate change, thereby attracting additional investors [93]. ERBD is an entity that works with other financial institutions, both international and domestic, to offer money for projects that would be difficult to support on the free market. It specifically supports projects that encourage the private sector and enhance local economic circumstances by assisting SMEs [94].
  In addition to classic loans from banks, alternative instruments are *Municipal* and *Green Bonds*. Municipal bonds are issued by local authorities and administrations to raise funds to be used in their territory to finance projects, infrastructure operations and other public interest objectives [95]. Green bonds, on the other hand, are a novel instrument used to raise funds for environmentally friendly initiatives, notably in the smart city sector. These bonds were first introduced in 2007 and have increased in popularity since then, particularly after important international events such as Cop21 in Paris (2015) highlighted the significance of investing in environmentally friendly technology and initiatives. Initially, new bonds were issued mostly by supranational financial organizations such as the World Bank and the European Investment Bank, however, bonds issued by private enterprises, municipalities, and state agencies also entered the market. They function similarly to loans in the sense that the bond issuer accepts funds from investors and promises to

repay them with interest after a defined period of time. What distinguishes Green Bonds from the others is that the funds obtained must be utilized for green initiatives such as renewable energy, energy efficiency, sustainable management of natural resources like water and trash, and ecologically friendly building. Clearly, the transparency that issuers must offer on the project is crucial and is especially effective for recruiting investors who care about sustainable practices [96].

- **Equity Financing:** it is a method where investors provide funds by purchasing shares of the company that wants to invest in a project. Those who hold these shares can earn in two ways: by receiving a portion of the company's profits, called dividends, or if the value of the shares increases over time. The source of this money can come from project sponsors, private investors, or even the government, so it can be of both public and private nature [92].

Concerning the term funding, as mentioned above, it is key to focus on funds from the European Union. The most relevant sources to highlight are the following:

- **Horizon 2020:** it is an extensive funding programme created by the European Commission to promote and support scientific research and innovation within the European Union. With a budget of about €80 billion for the period 2014-2020, it was designed to advance the goals of the Europe 2020 agenda by stimulating scientific and technological progress across Europe. The programme is organized into three main areas, called pillars, each with specific goals and areas of interest:
    - *Excellence Science*: it focuses on raising the level of European science, making Europe a global leader in scientific research.
    - *Industrial Leadership*: it aims to make Europe an attractive destination for research and innovation investments, supporting the growth potential of European companies. It includes funding for advanced technologies, access to venture capital, and support for innovative small and medium-sized enterprises (SMEs).
    - *Societal Challenges*: Aimed at addressing major global issues through research, this pillar covers areas such as health, sustainable agriculture, clean energy, sustainable transport, and resource efficiency.

  In addition to the three pillars, Horizon 2020 also includes other cross-cutting programmes that support various research and innovation activities like the *European Institute of Innovation and Technology (EIT)*. Horizon 2020 is open to a wide range of participants, including companies, universities, research centers, and other entities located in one of the EU member states or in associated or third countries. For an entity looking to access funding, the steps include searching for a suitable funding call on the participants' portal, finding project

partners if necessary, registering the organization on the H2020 portal, and submitting the project proposal. Submitted proposals are evaluated by a committee of experts who review the scientific excellence, potential impact, and quality of the project's implementation. Proposals that score the highest are selected for funding. The process from submission to the final funding decision can take about 5-6 months. Once selected, the proposals receive a grant agreement detailing the activities to be carried out, the budget, the duration, and other administrative and legal details necessary for the initiation and management of the project [97], [98].

- **Horizon Europe**: it is the European Union's leading programmes following Horizon 2020. It has a financial allocation of €95.5 billion and is dedicated to fostering innovation and research from 2021 to 2027. Horizon Europe aims to enhance advanced research and technological development across Europe by accelerating ecological and digital transitions with a focus on human-centered technology development. Additionally, it aims to protect biodiversity and sustainably manage natural resources to ensure food security and a healthy environment. The general goal is also to make Europe a sustainable, digitally advanced, and climate-neutral economy by transforming its energy, mobility, and production systems.
  Horizon Europe is structured around three main pillars:
  - *Excellence in Science:* it focuses on enhancing fundamental research, attracting top talent to Europe, supporting emerging researchers, and improving research infrastructure.
  - *Global Challenges and European Industrial Competitiveness:* this pillar expands and integrates themes from the previous Horizon 2020 programmes, organizing into six interdisciplinary areas covering topics such as health, social inclusion and culture, civil security, digitalization, climate, energy, mobility, and bioeconomy.
  - *Innovative Europe:* Promotes all forms of innovation, with a particular focus on small and medium-sized enterprises, supporting the development and commercialization of innovations.

  Horizon Europe sets clear goals through the introduction of 5 missions aligned with the SDGs of the United Nations 2030 Agenda, among which the most relevant in the smart city area are those related to adapting to climate change and creating climate-neutral cities. The programme also promotes international cooperation by allowing entities from non-EU member countries to participate and it includes entities such as the *European Innovation Council (EIC)* and the *European Institute of Innovation and Technology (EIT)*. The EIC, in particular, was established to stimulate radical and disruptive innovation, dedicating at least 70% of its budget to SMEs. It focuses on developing advanced technologies and supporting high-risk pioneering projects with market transformation potential.

Finally, Horizon Europe places a strong emphasis on open innovation, open science, and the need to make research accessible and reusable. This translates into the requirement that all scientific publications are freely accessible [99].

- **European Institution of Innovation and Technology (EIT)**: it is a parallel component of Horizon Europe, designed to foster overall innovation and economic growth by linking education, research, and entrepreneurial development. The primary goal of the EIT is to form innovative environments that can nurture and support new entrepreneurs and aid in the development of startups and SMEs. Additionally, the EIT works with other EU initiatives and uses various funding schemes to extend its impact and reach [100].
  Specifically, the *EIT Urban Mobility* initiative, launched in 2019, aims to revolutionize urban transportation by improving how people, goods, and waste are moved around cities, leading to enhanced urban livability. The key is using cities as "living labs". This initiative has been allocated funding of €1.6 billion and is made up of a consortium of 48 partners selected by the EU, among which the cities of Amsterdam, Barcelona, Copenhagen, Eindhoven, Hamburg, Helmond, Helsinki, Istanbul, Munich, Prague, Stockholm. In the Italian context, Milan is the only one participant, collaborating with AMAT and Polytechnic of Milan [101].
- **European Regional Development Fund (ERDF):** it is a structural fund of the European Union designed to support the EU's regional policy and to reduce disparities among member countries. It aims to foster economic growth in disadvantaged European regions [102], [103]. Unlike Horizon 2020 and Horizon Europe, the ERDF is considered to be indirectly managed, meaning that it is co-financed by programmes and calls launched by regional (ROP) and national (NOP) management authorities. The National Operational Programme (NOP) operates on a national level, defining a series of reforms and infrastructure projects determined by the state on how to distribute European funds. On the other hand, the Regional Operational Programme operates at a regional or local level, where European resources are directly assigned to local administrations responsible for their management.
  Since the calls are managed in the native language of the managing authority, they are more accessible to small and medium-sized enterprises. Moreover, the fact that the approach is defined locally allows for pursuing objectives that are more tailored to the specific situations of the territories involved [104]**.** Specifically, the areas in which the programme of this fund develops during the period 2021-2027 are as follows [103]**:**
    - *Innovation:* it promotes the development of advanced technologies such as augmented reality and solutions that enhance connectivity and communication. These innovations aim to make public services more efficient while ensuring they are accessible to everyone.

  - *Sustainability:* commits to increasing investments in projects that reduce carbon emissions, support the circular economy, and contribute to mitigating the risks associated with climate change.
  - *Mobility:* Aims to create a more connected Europe, breaking down geographic, economic, and social barriers to foster greater integration among regions.
  - *Inclusiveness:* funds are directed to projects that promote the social inclusion of all European citizens, including those related to employment and the support of social rights.
  - *Development*: the programme aims to bring Europe closer to its citizens by fostering the integration and convergence of urban areas through support for local initiatives.

- **Next Generation EU:** it is a temporary economic recovery initiative designed to mitigate the impacts of the pandemic and push EU economies toward a greener, more digital, and resilient future. In fact, the broadly defined objectives are ecological transition, macroeconomic stability, digital transition, and equity. With a financial commitment of €806.9 billion, this fund has been integrated into the EU budget for the 2021-2027 period and is available to all member states [105]. Most of the Next Generation EU funds, about 90%, are allocated to National Recovery and Resilience (PNRR) plans through the Recovery and Resilience Facility (RRF), totaling €723.8 billion. These funds are assigned to various countries based on their specific needs [106]. In addition to the RRF, the financial package of Next Generation EU also supports other existing programmes like React-EU, which has been allocated €50.6 billion, and Horizon Europe, which has received €5.4 billion [105]. Focusing on the RRF, it is an instrument created by the European Commission to raise funds borrowing on the capital markets [107]. It offers grants, totaling €338 billion, which do not need to be repaid, and loans, amounting to €385.8 billion, which must be repaid by the beneficiary countries. The repayment of loans initiated with Next Generation EU funding will begin in 2028 and continue until 2058. To ensure favorable loan conditions and maintain a high credit rating, the EU uses part of its budget as a guarantee. It is important to note that, as detailed previously, loans will be repaid by member states, while grants are funded directly from the EU budget. Furthermore, the EU is financing up to 30% of the Next Generation EU plan by issuing green bonds, aimed at supporting environmentally friendly projects. This strategy will position the Commission as one of the leading issuers of green bonds globally [108].
  Focusing on the PNRR, Italy will receive €191.5 billion from the EU, of which €122.6 billion is in loans that will need to be repaid. The remaining €68.9 billion is provided as grants. Six missions have been identified for the implementation of the Italian National Recovery and Resilience Plan (PNRR) [109]**:**

1. Digitalisation, innovation, competitiveness, culture and tourism
2. Green revolution and ecological transition
3. Infrastructure for sustainable mobility
4. Education and research
5. Inclusion and cohesion
6. Health

Among the six missions, the most important ones that directly impact the smart city theme are Missions 1, 2, and 5. Mission 1 allocates €2 billion to promote digitalization, focusing on initiatives such as Mobility as a Service (MaaS) and the digitalization of public administrations. Mission 2 impacts a wide range of solutions including Renewable Energy Communities, smart metering, and smart grids for optimized and waste-free electricity distribution. This mission also includes projects for territory monitoring using technologies to prevent risks. A total of €2.2 billion has been allocated for Renewable Energy Communities, €4 billion for smart grid projects, and €6 billion for territory enhancement projects that include energy efficiency solutions.

Finally, Mission 5 allocates €9 billion for Urban Regeneration. Of this, about €2.5 billion are designated for the intervention "Piani Urbani Integrati", aiming to develop participatory urban planning projects to create sustainable, innovative, and inclusive cities. The goal is to create synergies between metropolitan cities and neighboring smaller municipalities, filling infrastructure and mobility gaps. Included in the €9 billion for urban regeneration are also €2.8 billion for the solution "Programma innvovativo della qualità dell'abitare" aimed at rehabilitating degraded areas and building new public housing [110].

1.2.6. Market Parameters

In order to provide a comprehensive view of the Smart City market, two key parameters were analyzed: market value and market size. The market value represents the sum of the market valuation of all companies operating in the sector, while the market size represents the revenues generated from the sale of the products and services implemented in the smart city.

1.2.6.1. Market Value

According to a recent analysis by Grand View Research, the current market value of smart cities is $747.7 billion [111], and a bright future lies ahead for the sector, with market value expected to grow to $3,728.3 billion by 2030 [112]. This expansion, characterized by a CAGR of 25.8% over the period from 2023 to 2030, is powered by a combination of favorable government policies and technological advancement in key areas such as artificial intelligence, big data processing, cloud computing, and the Internet of Things [113]. In the context of the smart cities market, the United States stands out as the most flourishing market, holding 30.4% of the total market share, while Europe, in 2022, showcased a market value of $190.72 billion, underscoring the significant impact of European government policies in propelling the development of the smart city framework [111].

1.2.6.2. Market Size (Revenue)

Statista has projected that the global Smart Cities market will achieve a revenue of $104.80 billion by 2024. This upward trajectory is expected to endure, as it is anticipated to grow at a CAGR of 12.15% until 2028, ultimately resulting in a final market size of $165.80 billion [114].

About Europe, the revenue is projected to reach $29.78 billion by 2024, highlighting the vast opportunities available in the region. Additionally, it is predicted that the market will experience a gradual rise, with a CAGR of 11.48% between 2024 and 2028, culminating in a value of $46.00 billion by 2028. This significant growth trend means an increasing demand and acceptance of smart city technology and solutions throughout Europe, supported also by European Union funding initiatives [115]. Shifting focus to Italy, it is estimated that by 2024, the revenue generated by this sector in the country will amount to $1.31 billion. This positive growth trend is expected to continue at a compound annual rate of 10.31% between 2024 and 2028, resulting in $1.94 billion by 2028 [116]. The growth is supported also by the PNNR funds coming from the broader European plan “Next Generation EU”.

2 Objectives and Methodology

This chapter aims to thoroughly explain the objectives of the thesis and the methodological flow used for its composition. It is organized into four main parts that reflect the core areas of the entire work. The first section is dedicated to the objectives and research questions pertaining to the entire study. The second section provides an explanation of how the introductory literature review chapter was approached and the last two section are focused on the detailed description of the central part of the thesis, namely the creation of a database containing smart city projects scattered throughout Europe, and the analysis methods employed on it to map the state of the art situation in Italy and Europe.

2.1. Objectives

The primary goal of this thesis is to explore, analyze, and meticulously map the state of the art of smart city projects in Europe and Italy. This necessitates a precise definition of the "Smart City" concept, capturing all its nuances and deeply diving into related topics such as application fields, investments, relationship with the United Nations' SDGs, and key technologies for the implementation of this paradigm. Creating a detailed Excel database, compiled through specific research on smart city projects, it has been possible to generate insights on various aspects. Among these, the mapping of the distribution and characteristics of projects over time and space stands out, with particular attention to application fields geographical and temporal trends. The thesis also explores the funding dynamics of these projects, analyzing the types of investment and the total associated costs, especially concerning projects supported by the European Union. Additionally, the analysis extends to the benefits derived from smart city projects, assessing their impact on various application sectors and their contribution towards achieving the SDGs. Another crucial aspect is the examination of citizen engagement in the projects, essential to ensuring that smart city initiatives are inclusive and responsive to community needs.

Summarizing, the main research question of the thesis is:

"What is the state of the art of Smart City projects in Europe and Italy?"

Of course, this research question incorporates the multiple aspects described at the beginning of this section. Therefore, it is possible to identify derived research questions:

- RQ1: *"What is the temporal and geographical distribution of smart city projects in Europe and Italy, and which are the most developed application fields?"*
- RQ2: *"What are the main sources of investment for smart city projects, and how are these funds distributed among various application fields?"*
- RQ3: *"Which are the main technologies used in smart city projects?"*
- RQ4: *"How data are used in smart city projects?"*
- RQ5: *"Which are the main benefits of the projects, and which are the most impacted SDGs?"*
- RQ6: *"What is the degree of citizen involvement in smart city projects, and what forms does this involvement take?"*

These questions are addressed through the use of analytical methods based on specific indicators which will be presented later in this chapter, allowing for a detailed and quantifiable understanding of the dynamics and impacts of the projects.

2.2. Literature review methods

As expressed in the introductory lines of *Chapter 1*, the literature review has the main aim to provide the reader with a broad understanding of the most significant themes within the smart city context. Initially, it addresses the topic of IoT technology, identified as crucial for the implementation of the smart city paradigm, also explaining how it relates to other fundamental and complementary technologies such as AI, Big Data, Cloud, and Edge Computing. Once the most widely used technologies were understood, it became possible to delve into the concept of the Smart City, exploring a variety of topics including application fields, relationships with the Sustainable Development Goals, and the methods through which projects are financed.

To write this part of the thesis, it was essential to carry out research for academic articles as can be seen in *Figure 6*.

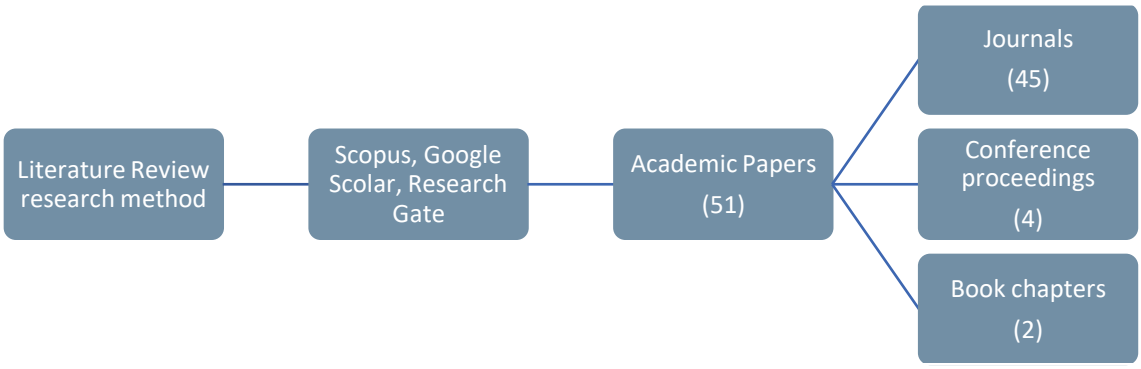


Figure 6: Literature review research method

Using dedicated search engines such as Scopus, Google Scholar, and Research Gate, 51 academic papers were used, including journals, conference proceedings and book chapters, showing that the scientific literature on Smart Cities and IoT is very rich. The most commonly used keywords were the following:

- "Smart City"
- "Smart City" AND "Definition"
- "Smart City" AND "Enabling technologies"
- "Smart City" AND "Application fields"
- "Smart City" AND "Benefits" AND "Challenges"
- "Smart City" AND "Sustainable Development Goals"
- "Smart City" AND "Europe"
- "Internet of Things"
- "Internet of Things" AND "Smart city"
- "Internet of Things" AND "Architecture"
- "Big Data" AND "Smart City"
- "AI" AND "Smart City"
- "AI" AND "Internet of Things"

In addition to academic articles, other types of sources were used to investigate topics such as the market values of Smart Cities, market valuations of IoT technology, financing methods for smart city projects and their application areas. These included reports from the Milan Polytechnic Observatory, reports from consultancy firms such as Deloitte, websites of European Union bodies like the European Commission and portals specialized in market research, such as Statista. This approach was adopted to ensure access to the most up-to-date information and to avoid the risk of presenting outdated and no longer relevant data.

2.3. The database creation

The creation of an Excel database containing useful information for analyzing the state of the art of smart city projects in Europe and Italy is the main part of the thesis work. This section presents the methodology followed for its creation, its structure, the sources used to fill it, its integration with the existing database of the Polytechnic of Milan's Smart City Observatory, and the standardization process required to carry out subsequent analyses.

2.3.1. The structure

To determine the most important elements for creating the database columns, the Smart City Observatory database from Polytechnic of Milan was used as a reference. This approach ensured that if the decision to integrate the data of the two databases at the end of the projects research was made, it could be done seamlessly, avoiding lengthy procedures to standardize them.

In the following detailed description of the database structure, it's crucial to note that each row in the Excel sheet represents a single smart city project described through different information by the columns names. These columns are divided into two categories: those that are in common with the Observatory's database and the additional ones that explore new analytical dimensions. The columns that match those of the observatory's database include:

- **Use case name:** it represents a specific case of implementation in a project. It's important to note that within a project there can be multiple use cases.
- **Project name:** it identifies the name of the project. Very often, a project includes several use cases, especially when we talk about projects funded by the European Union. Thus, this column allows for easier identification of large-scale projects.
- **Investment description:** this column provides an extensive description of the methods through which the project is financed. However, this information can often be challenging to obtain, so this field is frequently filled with "N/A". The financing methods for projects originating from the European Union are more readily available and detailed. In such cases, this column often indicates how much funding the European Union has provided towards the total amount needed to complete the project.
- **Total cost:** it shows the total amount needed to complete the project when the information is available. Similar to the previous column, there are several cases where this data is not obtainable and thus codified with "N/A". The currency used to express the total cost is the euro, and if the project amount is originally in other currencies, it is converted to euros.
- **Investment typology:** this column was created to define the type of investment source for the projects. Projects' investments can be classified into private, public, or a combination of both. To elaborate on each one:
    - *Private:* this type involves financial support sourced exclusively from private entities. It can include individual investors, private companies, or non-governmental organizations. Private funding is often used when projects aim for profit or when they align with the strategic interests of the investors.
    - *Public:* This type of funding comes from governmental sources. It is the case of local, regional, or national government funds. Moreover, it could

be also supranational as in the case of European Union Funds discussed previously in *section 1.2.5*. Typically, it is something allocated to projects that are intended to serve the public interest.

- *Public and Private:* this classification encompasses initiatives that are supported by a combination of financial contributions from private and public entities. It is commonly employed for extensive projects that have significant effects on the community and demand substantial financial support, which may exceed the capacity of a single funding source. This strategy facilitates the distribution of risks and resources among the public and private sectors and implies collaboration between parties also in the revenue sharing model.

- **Participants:** it illustrates the various actors involved in the execution of the project, and this does not mean that they have to necessarily fund the project. Therefore, this column includes names of companies as well as governmental entities at all levels. This could range from local municipalities to regional, national and supranational entities, depending on the scope and scale of the project. Additionally, private companies, whether they are large corporations or small businesses, can also play crucial roles, particularly in providing expertise, resources, or financial backing. Non-profit organizations and community groups are also sometimes involved, contributing to the project's development and implementation with their unique perspectives and objectives. In this way it is possible to clarify who is responsible for various aspects of the project and how these different contributors collaborate towards achieving the project goals.
- **City Name:** identifies the name of the city in which the project is developed. In some case it is not available since the project is developed on a wider area and thus falls in the categorization of smart land, as it will be explained in "Project extension" column.
- **Region:** the column presents the name of the region in which the city is located. It identifies regions only in the case of Italian territory and it has been introduced to give the possibility of developing more detailed analysis for Italy.
- **Geographic area:** it simply represents the continent of origin of the city or country where the project is carried out. Since the thesis focuses on the European region, all projects within the database are tagged as "Europe". However, the column could be useful in the future if there is an interest in extending the geographical scope of the analysis.
- **Nation:** it identifies the nation in which the projects are developed.
- **Project extension:** it indicates whether the project is classified as "City" or "Land." "City" means that the project's application area is confined within the city limits, while "Land" suggests that the project covers broader territories, such as the implementation of a smart grid across the Valle d'Aosta region,

which encompasses 69 Italian municipalities, as detailed in the example provided for the application field "Smart Metering & Grid" in *subsection 1.2.2*.

- **Application field:** defines the application field of the project. Thus, each project can be categorized based on the areas shown in *section 1.2.2* of the introductory chapter of the thesis. Specifically, the eleven application fields considered include Smart Mobility, Smart Lighting, Smart Waste Management, Smart Environmental Monitoring, Smart Agriculture, Smart Building, Smart Metering & Grid, eHealth, Smart Tourism, Smart Security, Smart Governance.
- **Functionality:** it specifies the project functionality identified earlier in the "Application field" column. Within each application domain, various types of solutions can be identified, allowing for detailed descriptions. An example could be applied to the field of Smart Mobility, which includes several functionalities such as the purchase of green public transport vehicles, sharing solutions, smart parking solutions, MaaS solutions, and more.
- **Progress status**: this column displays a categorization of the projects based on their progress status at the time they were entered into the database. The classification includes pilot projects, executive projects, and preliminary economic or technological analyses. Detailing these three elements:
    - *Pilot projects*: experimental projects intended to test the feasibility and effectiveness of a concept or technology in a controlled setting before it is rolled out on a larger scale. Pilot projects are typically smaller in scale and scope, allowing project managers to identify potential problems and assess the possibility of expansion. In the context of European Union projects often there are many pilot cities where the solution is tested. After that, the results are used to create best practices and implement similar solutions on a broader scale.
    - *Executive projects*: projects that have moved beyond the pilot phase and are in the process of being fully implemented on a larger scale. At this stage, the project is actively being executed, with resources allocated and activities performed to meet the project objectives. Executive projects are usually fully funded and have clear objectives and timelines.
    - *Preliminary economic and/or technological analysis*: this category includes projects that are in the early stages of development, where the focus is on assessing the economic viability or technological requirements of the project. These analyses help determine whether the project should proceed to the pilot stage or if adjustments are needed to ensure success. They involve detailed studies that evaluate costs, benefits, risks, and the technological framework necessary for the project.
- **Start year**: identifies the year in which the project started.
- **End year**: identifies the year in which the project concluded. This data is related only to pilot projects.

- **Description:** in this column, a comprehensive and focused description of the solution envisioned by the individual project is provided. It essentially serves as a summary of all the information contained in the other cells, presented in a narrative format. The description elaborates on the specific objectives, the intended impact, the technologies used, the target users and the benefits of the projects. This allows for a clear and detailed understanding of what the project entails, ensuring that the key elements of the project are easily accessible and understandable to the reader.
- **Source link:** it contains a list of links through which the material related to each project has been found on the web. A detailed description of this field will be provided in the next subsection dedicated to the sources.
- **Technology:** this column lists the technologies implemented within the individual projects, including, for example, IoT, AI, Big Data, Cloud Computing, Edge Computing, photovoltaic panels, drones, digital twins, 5G, and more. Several times a combination of technologies is used in a single project and thus they are mentioned separated by commas inside the cell. However, not all projects have this information detailed, in such cases, it is encoded as "N/A".
- **System Integrator/provider:** it identifies the company or organization in charge of integrating various technologies in the project or the ones that provide the technology itself. Here names of companies are detailed as for example A2A, Cisco, ATM, Nokia, Tim. There are projects in which the system integrator is represented by municipalities, public companies like ATM in Milan, universities or other type of organizations in charge of the whole project.

The previous described columns are in common with the Smart City Observatory database while the following ones have been introduced to extend the analysis dimensions:

- **Source type:** it defines where the information about each project is retrieved from. The main source type identified are online smart city databases, websites and the Observatory's Newsletter which have been categorized in this way:
    - *Bable:* online database of projects throughout the world.
    - *Smart Cities Marketplace:* European Commission's online database of projects funded by the European Union.
    - *Nordic Smart City Network:* database focused on project by Nordic European cities, namely Finland, Norway and Sweden.
    - *Forum Virium Helsinki:* City of Helsinki innovation company's database through which it is possible to retrieve projects active in Finland's capital city and linked with other ones.

  - *Smart City Observatory Newsletter:* received through biweekly e-mails, it highlights the most cutting edge projects present at the moment with the possibility of explore in detail the projects thanks to provided links of websites.
  - *Website research:* performed searching for project in different countries writing in the search engine.

The source type topic will be deepened in the next subsection dedicated to it.

- **Benefits:** this column consists of nine different columns that identify nine standardized recurring benefits in smart city projects. When a project includes a particular benefit, the corresponding column is marked with an "x". This method was chosen because projects can have more than one benefit, and this setup allows for an easy count of how many times each specific benefit is impacted. The identified benefits were:
  - *Benefit 1: Optimization in the management of energy/water/gas resources and waste reduction.*
  - *Benefit 2: Mobility improvement and traffic reduction.*
  - *Benefit 3: Increase in public safety.*
  - *Benefit 4: Service accessibility improvement.*
  - *Benefit 5: Well-being, health, and citizen experience improvement.*
  - *Benefit 6: Data-supported urban decision-making and planning.*
  - *Benefit 7: Environmental sustainability, reduction in pollution and CO2 emissions.*
  - *Benefit 8: Operational efficiency and reduction of operational costs.*
  - *Benefit 9: Economic growth support.*

  At the end of these nine columns, another one called “benefits description” is present to describe in a narrative and non-structured way why the project impacts the single benefit.

- **European Union involvement:** categorizing with a simple "Yes" or "No" this column aims to show whether a project has involved the European Union or not.
- **European Union funding source:** if the previous column about the European Union involvement is tagged with “Yes”, this one aims at indicating which are main sources through which the EU funds smart city project. The main funds are the ones presented in *subsection 1.2.5*, namely Horizon Europe, Horizon 2020, EIT, ERDF and Next Generation EU.
- **Data Usage:** this column defines how the data retrieved from the implementation of a project can be used. Specifically, a categorization in three exclusive levels has been used:

  - *For internal purposes:* it involves using data to optimize internal processes. It focuses on enhancing the efficiency of operations within an organization.
  - *To Provide Services to Citizens:* it involves optimizing existing services or introducing new ones for citizens. The goal is to improve the quality and availability of services offered to the public.
  - *Shared with Public or Private Entities:* this usage entails delivering new and more comprehensive services to citizens by leveraging a common data pool accessible to all stakeholders involved. This approach supports decision-making by providing a richer, shared data resource.
- **Data valorization:** the column aims to define how smart city projects create value from the data they possess in order to use it effectively in decision-making and operational contexts.
  As in the previous column, three modalities of data valorization have been identified:
  - *Descriptive:* data are used to understand what is happening but are not leveraged for planning. This type essentially provides a snapshot of the current state of applications without implying further analysis.
  - *Prescriptive:* this approach uses data to guide how to improve operations, with planning that optimizes decisions across various scenarios. Data helps refine choices and set guidelines to support public decision-making.
  - *Adaptive:* in this modality, data and planning become increasingly dynamic and flexible in real-time, also through the implementation of applications. The data are more dynamic and allow for high automation of public decisions, integrating new technologies such as AI.
- **Citizen engagement:** *chapter 1* frequently highlights the central importance of the citizen's role in the smart city context. For this reason, each project has been categorized with a simple "Yes" or "No" based on whether it involves active citizen participation.
- **Citizen engagement description:** this column is used to further specify in a narrative way why and how the project entails citizen engagement. Clearly it is compiled only when the previous column is tagged with “Yes”. Typically, a project includes citizen participation when apps or portals are developed for sharing ideas or feedback, and when workshops, conferences, and forums are organized to facilitate the free exchange of ideas. This approach fosters urban planning that begins with citizen co-creation, ensuring that their input and perspectives shape the development and implementation of projects. This method of engagement not only promotes transparency but also enhances the relevance and acceptance of projects within the community.

- **SDGs:** in this case, as for the benefits, 17 columns are used to define which of the 17 SDGs of the United Nations are impacted by the single project. Projects can affect multiple SDGs, so an "x" is marked in each relevant SDG column to signify its influence. Additionally, there is another column titled "SDGs Description" which provides a narrative explanation of how and why the project impacts the specified SDGs. This descriptive approach helps clarify the project's contributions to achieving these global objectives.

2.3.2. Sources and research methods

The sources used to identify smart city projects and to compile all fields of the database, as mentioned in the previous subsection, include online sources like Smart Cities Marketplace, Bable, Observatory's Newsletter, Nordic Smart City Network, and Forum Virium Helsinki. The research focused on projects dated from 2021 onwards to build the new database, as the Observatory's database already contained 1,529 projects from 2010 to 2022.

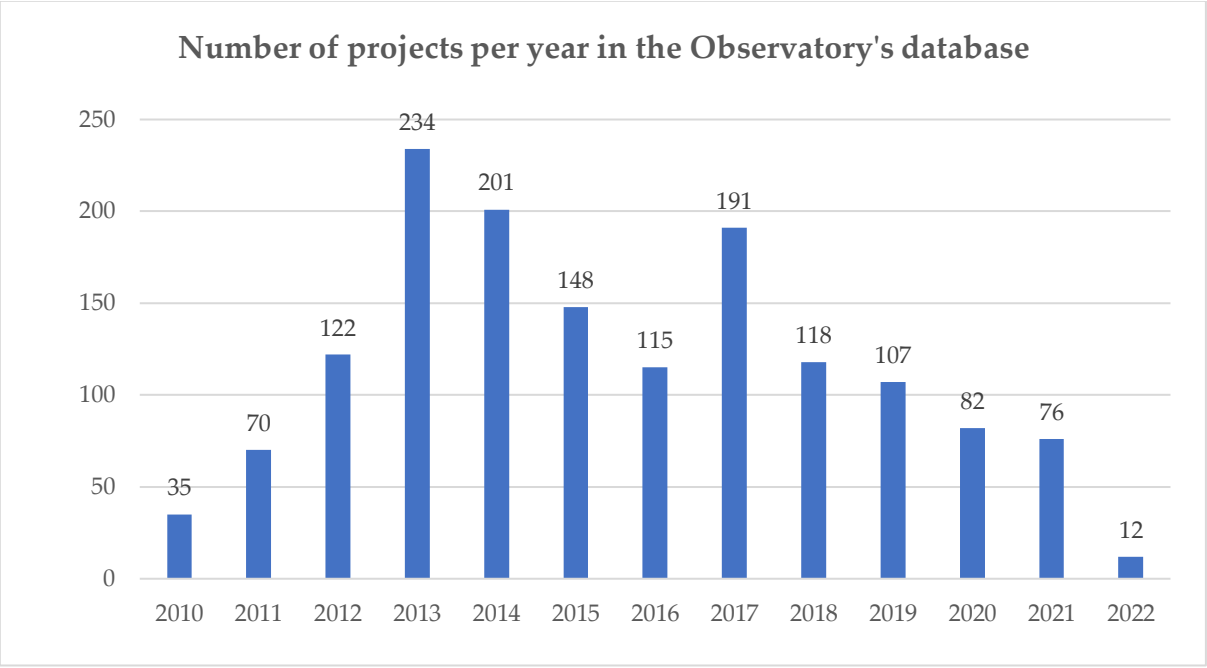


Figure 7: Number of projects per year in the Observatory's database

As shown in *Figure 7*, the projects in the Observatory's database from 2021 and 2022 were few, therefore it was decided to proceed with the research by including projects from these years as well, in order to make the database more homogeneous. As a consequence, the time span considered for all the research involved years from 2021 to 2024.

Delving into the specifics of the research methodology, the first website utilized was Smart Cities Marketplace[1], an online database by the European Commission that showcases major smart city projects funded by the European Union. By accessing the webpage, it is possible to sort the projects by type of application field, date, title, and stage of progress. Applying a filter to organize the projects from the most recent to the oldest, all projects from 2021 to 2024 were included in the excel database, particularly ensuring that those from 2021 and 2022 were not already present in the Observatory's database. A unique feature of this website is that it provides detailed information on funding from the European Union, which is particularly difficult to find on other websites or in online newspaper articles. However, the information about the project description most of times were generic since the projects reported in this web site are huge projects in which various cities are involved, usually pilot cities to test solutions and fellow cities in which the solution previously tested are implemented. To find a more detailed description about these big project the consequent approach was searching for the projects name on the search engine. Many times, it was possible to retrieve more detailed data thanks to the projects' official websites such as ASCEND, RESPONSE, SPROUT, TWINEU.

Once finished to gather projects from Smart Cities Marketplace, the next website used was Bable[2], which is an online repository of use cases throughout all the world. In fact the aim of this website is to learn from others' experiences and find solutions that could be replicated in various urban contexts. Generally, the website does not only provide a comprehensive collection of smart city projects, but it operates also as a networking portal allowing connection between cities and businesses, creating a knowledge-sharing platform. Bable revealed to be very useful since it is very comprehensive about the types of data included in its database, allowing to fill almost all the column of the thesis one. Specifically, it clearly indicates data related to the impact of projects on the SDGs, which is rare when searching through other portals. However, a limitation of the website is that information on the investments required for the projects is almost never available. Consequently, this has required additional research on other sites to find this missing data. Unfortunately, in most cases, it was still not possible to find information about this. Clearly, also in this case and all the typologies of research that will be described in this subsection, projects form 2021 onwards have been retrieved, following the same approach used for Smart Cities Marketplace.

The next phase of the research process involved using a very useful resource provided by the Smart City Observatory of the Polytechnic of Milan, namely its Newsletter. This consists of biweekly emails that gather the most interesting news in the Smart City field, highlighting the most significant technological and market trends, what types of projects are in execution or starting up, and administrative orders and actions by

[1] https://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects
[2] https://www.bable-smartcities.eu/it/explore/use-cases.html

government bodies. The news in these emails also include links to the original source of information, allowing for a deeper dive into the details of the projects mentioned. The great utility of this resource was demonstrated by its ability to uncover many recent projects, specifically for the years 2023 and 2024. However, it should be noted that information on investments was not always made available by websites. Moreover, most of the projects collected through the Newsletter are focused primarily on the Italian territory, although there are some news items and projects from other countries included.

Once collected all the possible projects from the Newsletter a brief analysis of the status of the database was conducted, understanding that a poor number of projects from the Northern Area of Europe was present. For this reason, it was decided to focus the research on this geographic area. Finding projects related to Scandinavian territories was quite difficult until three websites were found: Nordic Smart City Network[3], Forum Virium Helsinki[4] and Smart City Sweden[5]. Nordic Smart City Network is a collaboration among twenty cities from five Nordic countries: Denmark, Finland, Iceland, Norway, and Sweden. It aims to develop sustainable and livable cities by sharing best practices and innovations. The peculiarity of the website is a section dedicated to several smart city projects. Forum Virium Helsinki is Helsinki's municipal innovation agency. It collaborates with businesses, academic institutions, other governmental bodies, and the residents of Helsinki to shape the city's future. The organization's goal is to transform Helsinki into the world's leading example of a functional smart city. Also in this website there is a section dedicated to projects in which the organization is involved, which revealed to be comprehensive since data about investments are present and looking for projects in which Forum Virium Helsinki is involved it is possible to find big projects involving other entities and countries beyond Finland. Finally, Smart City Sweden is a governmental initiative that showcases Sweden's innovative urban solutions to the world. It serves as a platform for sharing sustainable city technologies and attracts foreign investments. The program allows visitors to explore Swedish projects in areas like energy, mobility, urban planning, digitalization, climate and environment.

In the final phase of the research, combinations of city names, countries, and application domains, all associated with the term "Smart City", were entered into Google's search engine. This approach enabled the discovery of a wide range of projects across various sectors. It was particularly effective in identifying initiatives in areas like eHealth and Smart Agriculture, which had previously been difficult to find using other methodologies employed. The exploration of smart city projects using this latest methodology led to the utilization of sources such as websites of companies

[3] https://nscn.eu/b
[4] https://forumvirium.fi/en/
[5] https://smartcitysweden.com/

producing cutting edge technologies, institutional sites including municipalities and national governments, and online newspaper articles focused on topics related to Smart Cities, sustainability, and innovation.

At this stage, the database proved to be quite comprehensive and rich, having reached a total of 472 projects. Specifically, the distribution of these projects based on their source is clearly indicated in *Figure 8*.

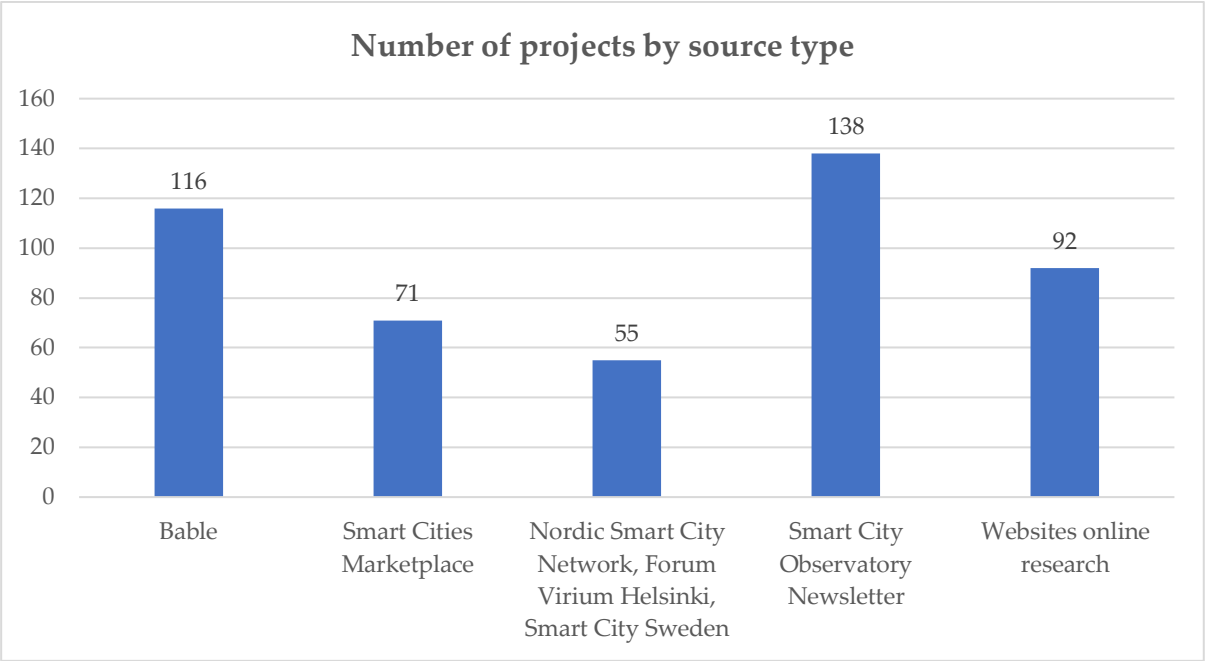


Figure 8: Number of projects by source type

2.3.3. Standardization Process

Once the data collection process was completed, to proceed with an effective data analysis, it was necessary to clean and standardize the format of the collected data. This step was crucial to ensure a faster and more consistent subsequent analysis, primarily using Excel and its pivot table features. The following bullet points list defines the most significant interventions conducted:

- **Accuracy errors management:** special attention was given to correct accuracy errors and spelling mistakes in key columns. These included columns like investment typology, city name, region, nation, project extension, application field, progress status, start year, technology, European Union involvement, European Union funding source, and citizen engagement. This careful checking ensured that the aggregated data was correctly interpreted by Excel when used

in pivot tables. A clear example is represented by the "Nation" column. Nation names were sometimes written inconsistently, with capitalization errors or extra spaces at the end, leading excel to mistakenly categorize the same country as three separate entries in the pivot table. To solve this issue, a method was used where the country name was selected using a filter, then copied and pasted with a uniform format across all occurrences, ensuring accurate and consistent categorization. This same method was successfully applied to the other columns mentioned to ensure data consistency.

- **Empty cells management:** the issue of empty cells, which was common in many columns, was especially evident in those concerning details like investment description, total cost and technology. Often, during the research phase, it was not possible to obtain data for these fields. To address this issue, in the mentioned columns the term "N/A" (not available) was used to indicate the absence of information. However, the same approach using "N/A" was consistently applied to other columns of the database as well. For instance, in cases where a project was identified as an initiative covering a broader area than a city, such as the smart grid project in Valle d'Aosta described in *subsection 1.2.2*, the "City" column was marked with "N/A". In fact, only the region, in this case Valle d'Aosta, was specified to indicate the location of the project. This method of managing empty cells ensures clarity and uniformity in the handling of missing data in the database.
- **EU funded project management:** in managing data related to large projects funded by the European Union, a specific problem related to the scale and complexity of these initiatives was encountered. These projects often involve multiple cities across different countries, making data management particularly challenging. The first step to address this challenge was to divide the project into multiple excel rows, assigning each to a specific intervention in a single city. In the "Project Name" column, the name of the larger project was indicated, while in the "Use case name" column, the specific intervention in each city was defined. This approach allowed for better organization and representation of data within the database. Regarding financial information, European Commission websites like Smart Cities Marketplace and Cordis generally provide only the total investment amount needed for the entire project and the portion financed by the European Union. Although this was useful for filling out cost-related fields, the main difficulty laid in determining the specific investment allocated to each involved country, as this information was often not available. To solve this problem, the "Investment description" column was detailed with the total amount invested and the portion provided by the European Union for the entire project, including the name and number of cities involved in the interventions. Subsequently, the methodology adopted for filling the "Total costs" column consisted in dividing the total project cost by

the number of cities involved, allowing to provide a specific value for each cell in the database.

- **Benefits and SDGs columns management:** the columns dedicated to benefits and SDGs were standardized using a consistent methodology, as described in the subsection dedicated to the database structure. Initially, for benefits, a single column named "benefits" was used, where the main benefits observed in each project were listed in a narrative form. Often, a project presented multiple benefits simultaneously. After entering all the projects and analyzing the descriptions, a recurring pattern emerged: the main benefits were frequently the same, and in many cases, they coincided with those defined in *subsection 1.2.3* dedicated to them. Consequently, by combining the information in the database with the ones from the literature review, it was possible to standardize the benefits into nine main categories, as described in the database structure. Nine distinct columns were then created for the benefits, while also retaining the original column for narrative descriptions, renamed "benefits description". This method significantly facilitated data analysis, marking with an "x" the columns corresponding to the benefits encountered, and more easily quantifying how often each benefit was impacted.
  For the SDGs, the same approach was pursued, using one column for narrative descriptions followed by 17 columns designated to be marked with an "x" if the project impacted a specific SDG.

2.3.4. Integration with the Smart City Observatory's database

At the beginning of *Section 2.3*, dedicated to the creation of the database, the existence of the Smart City Observatory database was mentioned. It was decided to integrate the data from it with those of the newly created database, including only projects from the year 2015 onwards. This decision was driven by the desire to use the historical depth of data for generic analyses on the start years of the projects, their geographic origins, and application fields. The integration of data from the observatory's database into the new database included only the common columns, facilitating the merger through a simple copy and paste of existing elements. This approach enabled the creation of a merged database covering the period from 2015 to 2024, effectively combining data from both databases. Subsequently, the same standardization process previously described was applied, ensuring the consistency of all data. During this phase, an additional standardization procedure was carried out by changing the name of "Smart people & living" application field of the observatory's database in "Smart Governance" in the new database. This change was motivated by the realization that, in the functionality column, it was clear that it referred to the same application area

"Smart Governance" of the new database. Finally, this merger operation increased the new database from 472 projects, those identified through the research process, to 1339 projects, covering the time span from 2015 to 2024.

2.4. Database analysis method

This section is dedicated to the methods and dimensions of analysis used to map as comprehensively as possible the state of the art of smart city projects in Italy and Europe, and to obtain significant insights about them. The first subsection is devoted to the analysis dimensions, while a second subsection focuses on the analysis tools used to conduct the analyses.

2.4.1. Analysis dimensions

The structure through which the analyses were conducted is divided based into thematic areas defined by different types of indicators, helping to face a deep and broad analysis on each aspect of the smart city context. The seven analysis dimension are the following:

- Temporal, geographical, and application field
- Investments
- Technology
- Data usage and valorization
- Benefits
- SDGs
- Citizen engagement

For the first two thematic areas, it was decided to integrate the database created for the thesis with the existing one from the Smart City Observatory of the Polytechnic of Milan, creating the *merged database* totaling 1,339 projects. Specifically, 472 new projects from 2021 to 2024 were found through the research work of this thesis while 867 projects from 2015 to 2022 were retrieved from the Observatory's database. Instead, for the subsequent five thematic areas, only the *new database* containing 472 projects was used (projects from 2021 to 2024). This choice derived from the fact that the first two thematic areas contain information specified with identically structured and formatted columns in both databases while the other five dimensions of analysis include data that have been categorized with completely new columns compared to

the Smart City Observatory database ones. For this reason, recompiling all the fields of these columns for projects from the Observatory's database would have been excessively time-consuming and complex.

Another key element to keep in mind in the analyses is that the mapping of the state of the art is divided into two levels, European and Italian. Therefore, whenever possible and deemed useful, the analysis of the indicators was conducted at both the comprehensive European level and the more precise Italian territorial level.
At this stage, it is essential to delve into the specifics of each thematic area, highlighting the indicators used to perform the analysis.

2.4.1.1. Temporal, geographical and application field analysis

The sample used for this kind of analysis is constituted by 1339 projects merging the two databases and resulting in a temporal time span between 2015 and 2024. The indicators included to perform the analysis are:

- **Number of projects per year:** indicator used to map the number of projects conducted each year from 2015 to 2024 in Europe.
- **Number of projects per year in Italy*:*** defines the number of projects developed each year within the Italian territory.
- **Number of projects per application field:** within the 12 application fields defined in the database structure, the indicator counts how many projects have been started for each.
- **Number of projects per application field In Italy:** same indicator of the previous one but focused on the Italian geographic area.
- **Project functionalities per application field:** this indicator aims at understanding which are the main functionalities present in the most important application field in terms of number of projects.
- **Number of projects per year for each application field:** for each application area, this indicator specifies the number of projects conducted annually.
- **Number of projects per year for each application field in Italy:** measures the number of projects for each application area annually within Italian territory.
- **Number of projects per nation:** count of projects conducted in each nation within the geographical area of Europe. Note that this refers to geographically European nations, thus also including the ones which are not members of the European Union.
- **Number of projects per Italian region:** it counts the number of projects in each Italian region.
- **Number of projects per application field for each nation:** it defines the percentage of projects in each application field for every nation. The aim is to understand which nation has the greatest interest in each application field.

- **Number of projects per city:** this indicator aims to count how many projects have been implemented in each European city.
- **Number of projects per Italian city:** it defines how many projects have been implemented for each Italian city.
- **Number of projects per application field for each city:** considering the most important cities in Europe, in terms of number of projects, the indicator explores which are the most important application fields.
- **Number of projects per application field for each Italian city:** considering the most important cities in Italy, in terms of number of projects, the indicator explores which are the most important application fields.

2.4.1.2. Investments analysis

The analysis was performed on 1339 projects merging the two databases for some dimensions of analysis, while only the new database with 472 projects was used to perform other analysis related to columns not present in the Observatory's database. Whenever deemed useful the same indicator was analyzed both for the European and Italian level.

The first part of this analysis is conducted with a sample of 1339 projects, namely the merged database, integration of the 2 databases for a period between 2015 and 2024.

- **Number of projects per investment typology:** considering private, public and the combination of the previous two investment sources, it calculates for each one which is the percentage of developed projects.
- **Number of projects per investment typology in Italy:** considering Italy it indicates for each investment typology how many projects have been developed.
- **Total cost per investment typology:** it sums the value of the investments for each investment typology.
- **Total cost per investment typology in Italy:** it sums the value of the investments for each investment typology in Italy.
- **Total cost per year:** it sums the value of the investments for each year, trying to find interesting trends.
- **Total cost per year in Italy:** it sums the value of the investments for each year, trying to find interesting trends in Italy.
- **Total cost per application field:** it sums the value of the investments for each application field.
- **Average cost per application field:** it gives insights about the average cost of a project in every application field.
- **Total cost per Nation:** it sums the value of the investments for each nation.

- **Total cost per Italian Region:** it sums the value of investment for each Italian region, giving useful insight about the ones with highest investments.

The second part of the analysis is conducted on a sample of 472 projects, namely only the new database comprising projects from 2021 to 2024 derived from this thesis research.

- **Number of projects funded by the European Union:** it calculates how many projects have been funded by the European Union.
- **Total cost of projects funded by the European Union:** considering the total value of the investments, it shows how much money came from the European Union.
- **Number of projects per European Union funding source:** it calculates how many projects have been funded by each European Union funding source.
- **Total cost of projects per European Union funding source:** it describes how much money came from each European Union funding source such as Next Generation EU, Horizon Europe, Horizon 2020 and ERDF and EIT Urban Mobility.
- **Total costs of project per application field for each European Union funding source:** considering the most important European Union's funding sources, the indicator maps how much money has been allocated to each application field.

2.4.1.3. Technology analysis

The sample used to perform this analysis is made up of 472 projects found through research analysis, namely the new database, for the period between 2021 and 2024.

- **Percentage of most frequently used technologies:** the indicator measure for each technology mentioned in the database, which is the % of usage in smart city projects.

2.4.1.4. Data usage and valorization analysis

The sample used to perform this analysis is made up of the 472 projects found through research analysis, namely the new database, for the period between 2021 and 2024.

- **Data usage distribution percentage:** it tracks the percentage distribution of data usage, categorizing it by whether the data were used for internal purpose, to provide services to citizens or to be shared with public or private entities.
- **Data usage distribution percentage per application field:** it has the aim of the previous analysis but focusing on each application field.

- **Data valorization distribution percentage:** it quantifies the percentage distribution of how data is valued, divided into the categories described in the database structure subsection, namely descriptive, prescriptive or adaptive.
- **Data valorization distribution percentage per application field:** it has the aim of the previous analysis but focusing on each application field.

2.4.1.5. Benefits analysis

The sample used to perform this analysis is made up of the 472 projects found through research analysis, namely the new database, for the period between 2021 and 2024.

- **Benefits impact frequency:** the indicator counts how many times a benefit is impacted.

2.4.1.6. SDGs analysis

The sample used to perform this analysis is made up of the 472 projects found through research analysis, namely the new database, for the period between 2021 and 2024.

- **SDGs achievement frequency:** it identifies the Sustainable Development Goals that are most significantly impacted by various initiatives. It provides a clear overview of which global goals are receiving the most attention in the realization of smart city projects, understanding which kind of application field contributed the most.

2.4.1.7. Citizen engagement analysis

The sample used to perform this analysis is made up of the 472 projects found through research analysis, namely the new database, for the period between 2021 and 2024.

- **Percentage of projects with citizen engagement:** it measures the percentage of projects that incorporate citizen participation.
- **Most used citizen engagement tools:** it categorizes the ways in which citizens are usually involved in projects.

2.4.2. Analysis Tool

In the pursuit of a structured and insightful analysis of smart city project data, this study employed various analytical tools to organize, summarize, and derive meaningful patterns from the dataset in an aggregated way. The key tool implied in this process was the pivot table, a powerful feature commonly used in Excel.

Pivot tables have been used to enable the segmentation of data based on various criteria such as the type of benefits impacted, the geographic distribution of projects, the application field distribution of projects, the frequency of certain outcomes and all the other analysis. For instance, by organizing data into a pivot table, it was possible to rapidly assess which application field was the most frequently impacted in terms of number of projects.

The use of pivot tables has significantly contributed to the efficiency and depth of analysis in this research, proving to be an indispensable tool in managing and interpreting the complex data involved in evaluating the impacts of smart city projects.

Clearly in the excel realm also many formulas were used to reorganize data a explore deeper the data organized by pivot tables. The typical example of the most used formula is VLOOKUP, which allowed to easily find in the large dataset the desired information.

3 Analysis and Results

This chapter of the thesis focuses on presenting the insights derived from the analyses conducted on various indicators defined in the previous "Objectives and Methodology" chapter. It is essential to note that the structure will precisely follow the one described in *subsection 2.4.1*, providing first a European overview followed by a more detailed Italian analysis for each indicator, when deemed useful. Therefore, the analysis dimensions which will be covered by several indicators will be the following:

- Temporal, geographical, and application field
- Investments
- Technology
- Data utilization and valorization
- Benefits
- SDGs
- Citizen engagement

3.1. Temporal, geographical and application field analysis

It should be noted that for this analysis section, data were sourced from the merger of the Smart City Observatory database of the Polytechnic of Milan and the database specifically created for this thesis. This encompasses a total of 1339 projects over a time span from 2015 to 2024. When deemed useful, the results of each indicator calculated on the European level was followed by a more focused analysis on the Italian territory.

3.1.1. Number of projects per year

The objective of this indicator is to analyze the temporal trend of smart city projects from 2015 to 2024 in Europe. On the 1339 projects, the data sample includes 1321 projects for which this information is available. The bar chart presented in *Figure 9* reveals significant annual variations in the number of projects, with an average of 132 projects initiated each year. There is a notable peak in 2017 probably due to the Climate Neutrality objectives defined by 2015 Paris Agreement, followed by a descending trend until 2020. That year recorded the lowest number of projects, likely due to the negative impacts of COVID-19, which shifted focus from smart city initiatives to fight the pandemic. From 2020, a clear upward trend is evident, reaching a new peak in 2023 with 191 projects. This increase can be attributed to substantial investments from the European Union, including funds from Horizon Europe, which has a much larger budget compared to previous Horizon 2020 programme. A significant contribution also came from Next Generation EU, launched in 2020, with the development of National Recovery and Resilience plans aimed at helping European countries to repair the economic and social damage caused by the pandemic. Probably also the maturity of the technological solution proposed in the smart city context played a crucial role. In 2024, the number of projects dropped to just over 100, falling below the annual average of 132. This decrease does not necessarily indicate a break in the positive trend of the previous years but is mainly due to the fact that data collection of the projects related to 2024 for this thesis was concluded in April of the same year.

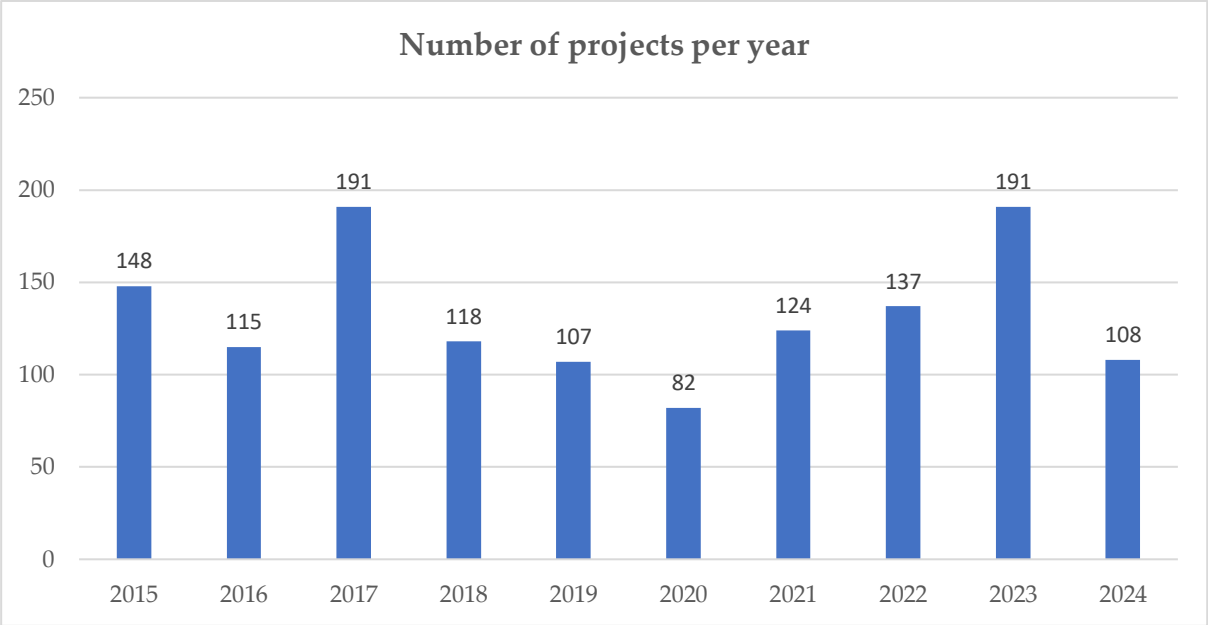


Figure 9: Number of projects per year

3.1.1.1. Number of projects per year in Italy

Figure 10 provides a detailed examination of the annual trend within the Italian context alone, as the thesis aims to offer an additional overview specifically focused on Italy. In particular, the number of projects initiated from 2015 to 2024 in Italy amounts to 389.

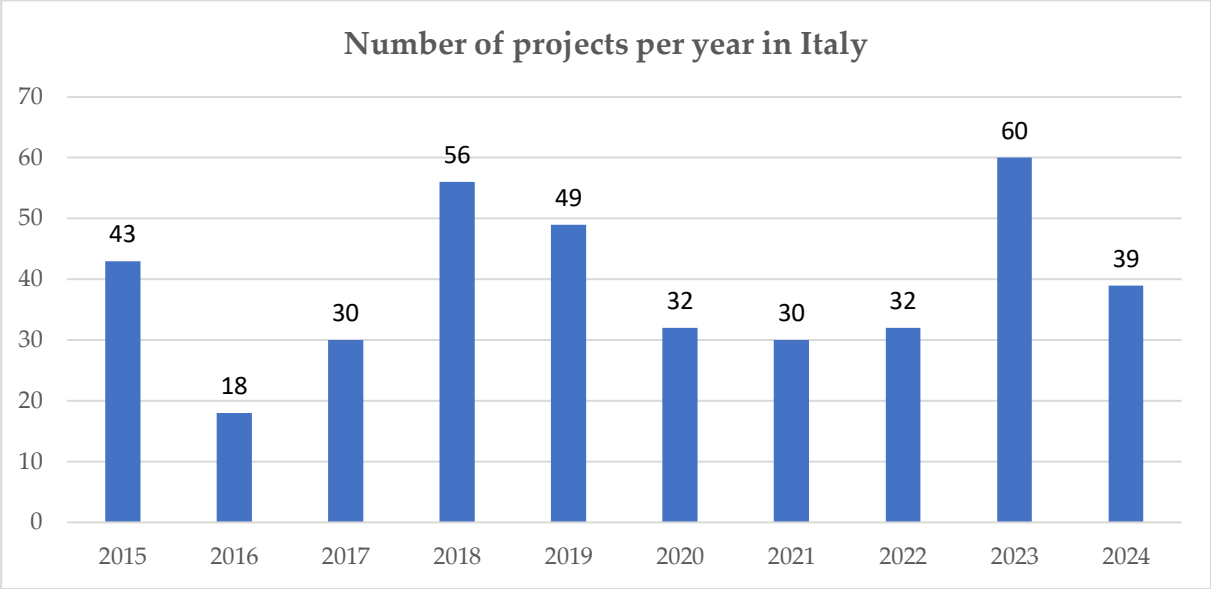


Figure 10: Number of projects per year in Italy

The situation, also in this case, illustrates numerous fluctuations in the number of projects. From 2016 to 2019, there is a noticeable upward trend in the number of projects, attributable to an increasing adoption of advanced technologies such as IoT, Big Data, and Artificial Intelligence. This trend could be explained also by the Climate Neutrality Goals defined by the United Nations with the 2015 Paris Convention. Subsequently, in 2020, this positive trend was interrupted, likely because of the pandemic, as was the case across the European context previously described. From 2021 onwards, the growth trend resumed, which can also be linked to European programmes like the Next Generation EU, particularly the Italian PNRR. The decline in 2024 is because, similarly to the previous European context, the data collection for projects stopped in April 2024.

3.1.2. Number of projects per application field

Considering the 11 application fields previously defined in the literature, it was possible to comprehensively map the number of projects implemented for each of them in the entire European territory. This mapping is shown in *Figure 11*. The available data on which this analysis has been conducted is 1339 projects, namely the entire merged database.

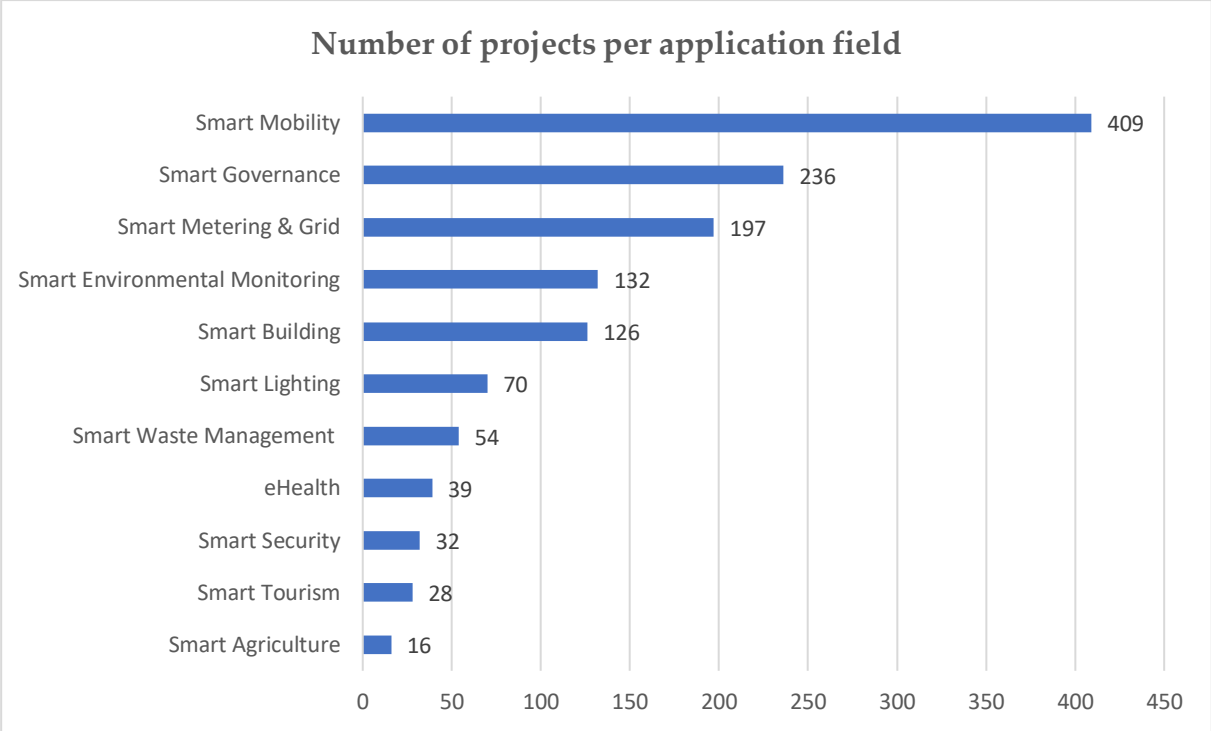


Figure 11: Number of projects per application field

The chart clearly shows that the category with the highest number of initiatives is Smart Mobility, totaling 409 projects. This category encompasses a wide array of mobility projects, including electric mobility, Mobility-as-a-Service, sharing services, micromobility, smart parking solutions and the use of sensors for traffic monitoring and management. The large number of projects in this category not only reflects the diversity of solutions included but also underscores the critical importance of this sector in enhancing urban livability and contributing to climate neutrality goals.

The second most significant sector is Smart Governance, with 236 projects. These include solutions such as digital twins, platforms, and applications to enhance access to municipal services and promote active citizen participation, making urban planning simpler and data driven.

The third most active sector is Smart Metering & Grid, with 197 projects. This field is gaining importance with projects aimed at developing smart networks that

incorporate smart meters, AI-supported management systems, and the virtualization of electrical networks, integrating the use of renewable energy through renewable energy communities. The sectors of Smart Environmental Monitoring and Smart Building also show a significant presence, with 132 and 126 projects respectively. In contrast, the sectors of Smart Tourism and Smart Agriculture appear to be less prioritized in the context of smart cities, with only 28 and 16 projects implemented respectively. Other application fields present a medium number of projects compared to the others.

3.1.2.1. Number of projects per application field in Italy

Using as sample the 389 projects coming from Italy, *Figure 12* shows that, once again, the largest number of projects focuses on the area of Smart Mobility, similar to the trend observed at the European level. However, in Italy, there is a growing importance of Smart Metering & Grid projects, followed by Smart Environmental Monitoring and Smart Lighting projects. Unlike the European trend, which places Smart Governance projects in second place, in Italy, only 35 projects have been recorded in this category, ranking it fifth, with the same number of projects of Smart Lighting. Once again, the Smart Agriculture application field ranks as last. This can certainly be attributed to the difficulty in finding such projects through research, and it does not necessarily mean that they are almost non-existent in the Italian landscape, which is, in fact, one of the agricultural excellences of Europe.

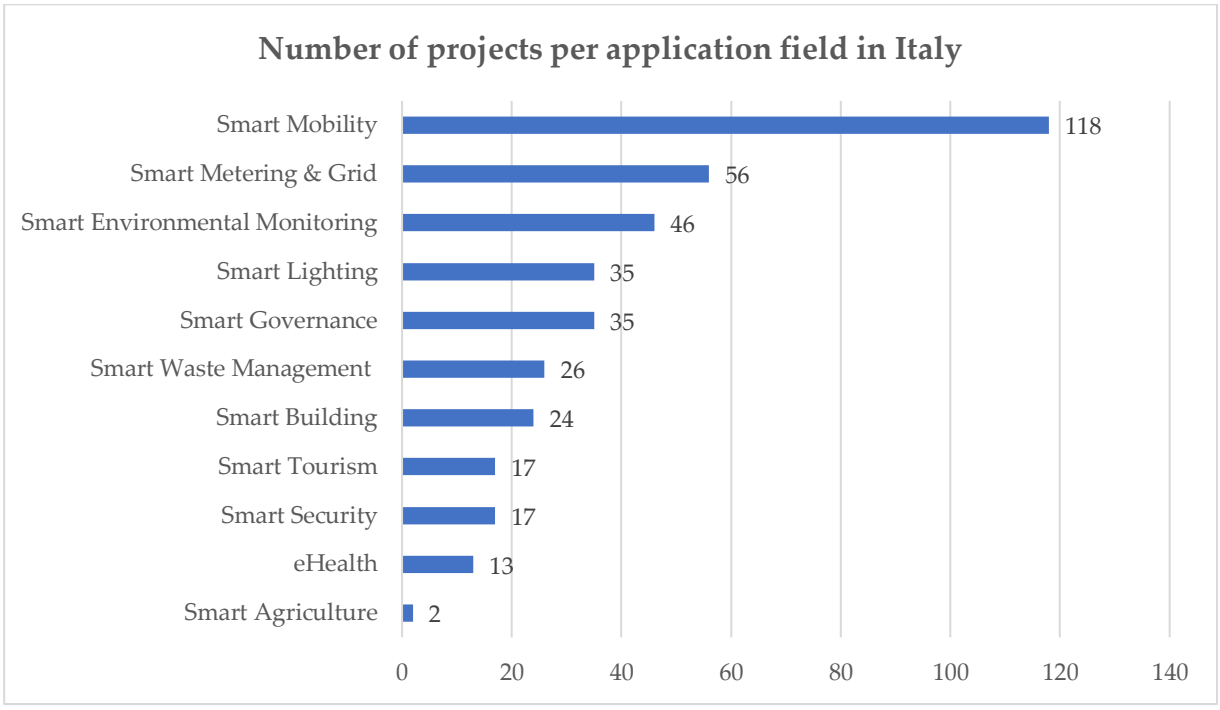


Figure 12: Number of projects per application field in Italy

3.1.3. Projects functionalities per application field

After examining the fields with the highest number of projects in the European context, it's interesting to explore the typical functionalities derived from implementing these solutions. This kind of analysis has been performed only on the 3 application fields, the ones with the greatest number of projects In Europe, namely Smart Mobility, Smart Governance and Smart Metering & Grid.

Smart Mobility has emerged as the field with the most projects (409 projects). However, this field is very broad and includes many functionalities. In Europe, the data about functionalities of this application field was available on 342 projects. In *Figure 13*, the most involved subdomains can be observed.

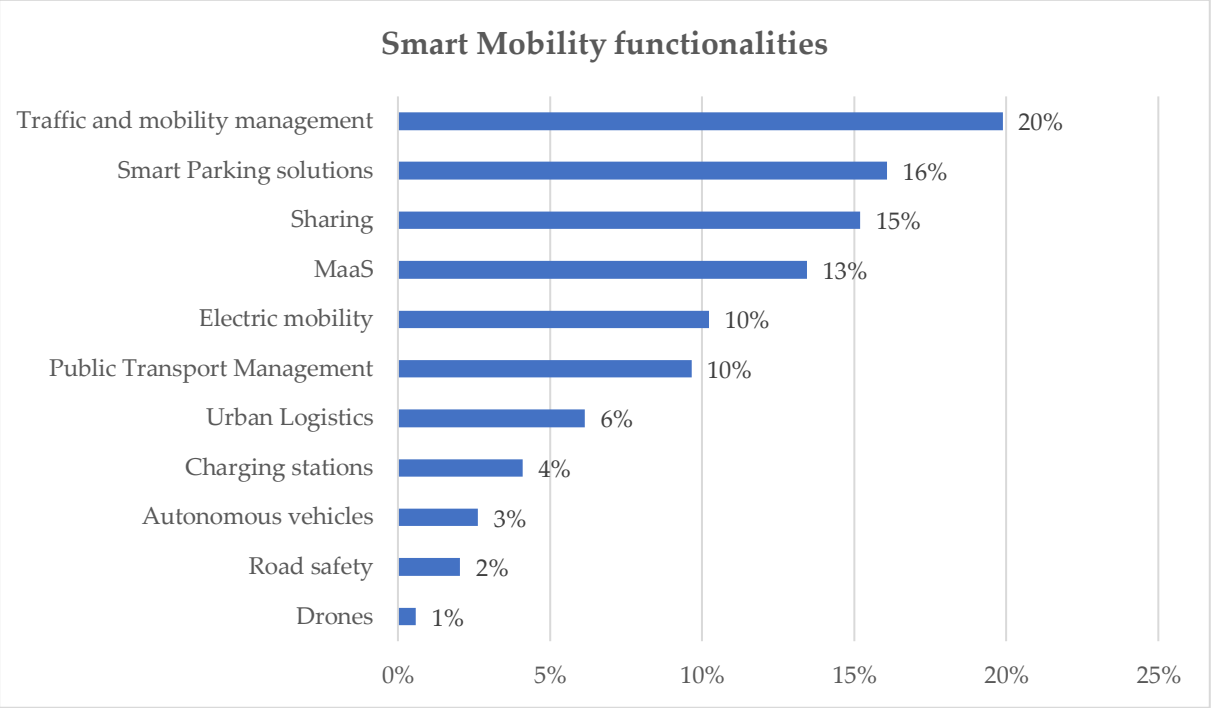


Figure 13: Smart Mobility functionalities

The functionality with the highest involvement, at 20%, is "Traffic and mobility management". This shows a strong focus on optimizing traffic, reducing road congestion, and generally improving urban mobility. This can be achieved through access control, digital models of city streets, monitoring traffic and pedestrian flow using AI, smart traffic lights, and data platforms for planning transportation.

Other significant areas are “Smart Parking solutions” (16%), “Sharing” (15%) and “MaaS” (13%). Smart parking solutions employ most of the time sensors to detect the availability of a parking spot, providing information and routing to application users. Sharing is a broad field that can include bikes, cars, scooters, and mopeds, most of which are electric. MaaS refers to the integration of multiple public and private

transportation modes (like sharing services and taxis) into a single digital platform. This platform allows users to plan, book, and pay for various services unifying services like buses, all types of sharing, trains, and taxis, offering a high degree of customization to citizens and typically promoting sustainable modes of transport. It also allows users to compare different travel options and choose the most convenient based on price and travel time.

"Electric mobility" accounts for a significant 10%, indicating that both public transport (trains and buses) and shared vehicles are becoming more sustainable. The interest in this area is also visible from the 4% related to "charging stations", which encourage the move towards this type of sustainable mobility.

"Public transport management", as the previous subdomain, stands at 10%, with solutions such as monitoring the number of passengers on buses, real-time monitoring of public transport, predictive models of transport demand, and gamification of public transport.

"Urban logistics", particularly last-mile delivery, has a notable value of 6%, including tests on urban delivery robots, urban delivery hubs, and sensor-equipped loading and unloading zones. The values for "autonomous vehicles" and the use of drones are still low, at 3% and 1% respectively, indicating that while tests have been conducted in these areas, there is potential for future growth. "Road safety" represents 2%, with elements such as smart pedestrian crossings and cameras to detect incidents.

In summary, the Smart Mobility sector shows a great interest in improving the experience of the citizen, having particular interest in sustainable solutions, with great interest in electric vehicles implementations.

Smart Governance emerged as the second most prominent application field with 236 projects. In Europe, on 236 projects in this application field, the data about the subdomain was available for 141 projects. *Figure 14* provides an insightful breakdown of the functionalities within this domain.

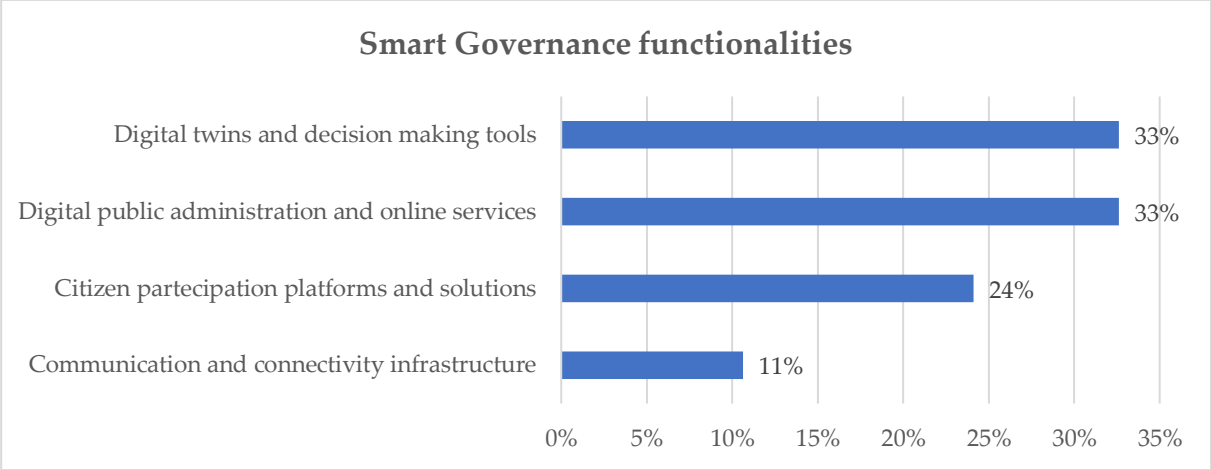


Figure 14: Smart Governance functionalities

The high percentages in “Digital twins and decision-making tools” (33%) reflect the growing use of digital twins across various domains. Digital twins, along with data dashboards and platforms, enable real-time data utilization for making more informed and safer decisions. They also facilitate the simulation of interventions, leading to better urban planning and management. This substantial focus on digital twins and decision-making tools underscores their importance in modern governance for optimizing city operations and infrastructure management.

The equal emphasis on “Digital public administration and online services” (33%) highlights a significant trend towards the digitalization of administrative procedures and the delivery of public services. Online platforms are being created to streamline administrative processes, provide transparent municipal activities, and improve citizens' access to services. This transition towards a more efficient and accessible digital public administration aims to make citizens more informed and involved in governmental activities, ultimately enhancing service accessibility and transparency.

C”itizen participation platforms and solutions” account for 24% of the projects, indicating a substantial focus on engaging citizens in governance. This involves apps for citizen engagement and feedback, workshops and educational meetings, and co-participation solutions for urban planning. The emphasis on citizen participation platforms and solutions highlights the drive towards a more participatory and inclusive governance model, where citizens have an active role in shaping their urban environment.

Although “Communication and connectivity infrastructure” has the lowest percentage, at 11%, it remains crucial. The introduction of 5G networks and public Wi-Fi infrastructure forms the backbone of digital services. These communication infrastructures facilitate the collection and exchange of information, enabling citizens to access digital services and participate in governance processes effectively. While communication and connectivity infrastructure might seem less directly linked to smart governance, it is fundamental in supporting all other functionalities by ensuring robust and reliable access to digital services.

The third and last analyzed application field is Smart Metering & Grid. In Europe, on the 197 projects registered in the database, the data about the subdomain was available for 130 of them. In *Figure 15* it is possible to observe the main functionalities in detail.

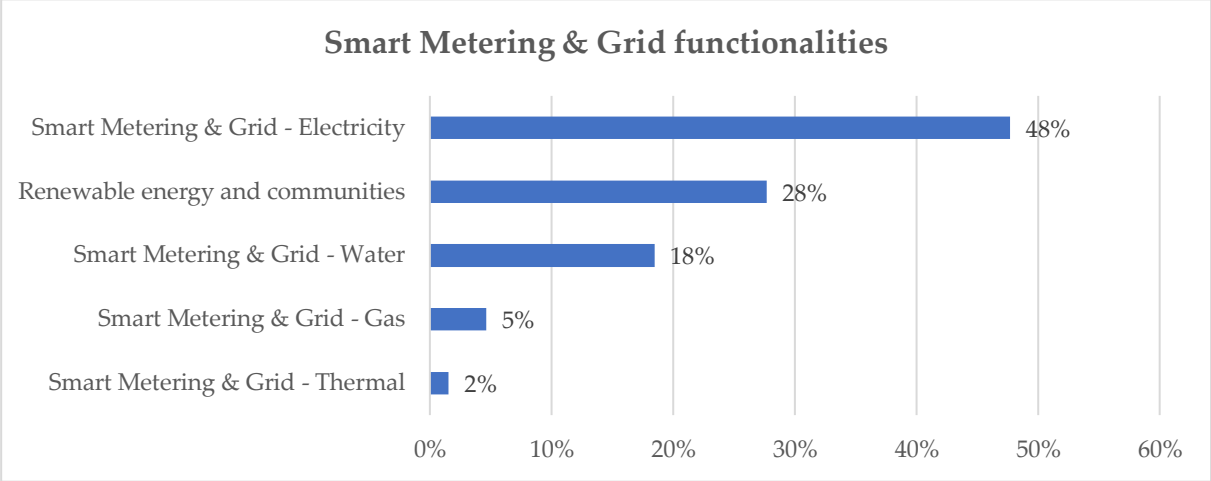


Figure 15: Smart Metering & Grid functionalities

The largest category, comprising 48% of the functionalities, is focused on electricity. This includes smart meters that provide real-time data on consumption, helping both consumers and utilities manage usage more effectively. Additionally, smart grids integrate digital technology to improve efficiency, reliability, and sustainability. For instance, creating a digital twin of the network system allows for real-time monitoring and simulation. This use of digital twins in electricity management highlights the importance of advanced simulations and real-time data to optimize grid operations, aiding in predictive maintenance, demand forecasting, and improving overall grid reliability. Generally, the significant emphasis on electricity underscores the importance of optimizing energy consumption and distribution, demonstrating a strong commitment to reducing energy waste, enhancing grid reliability, and integrating renewable energy sources.

"Renewable energy and communities" account for 30% of the functionalities. This category includes the integration of mainly photovoltaic panels into the grid, as well as initiatives that promote the use of local renewable energy and energy sharing within communities. The high percentage in this category underscores the growing commitment to sustainability and the transition to clean energy. Communities are increasingly playing a role in generating and sharing renewable energy, which can reduce dependence on fossil fuels and lower carbon footprints.

Smart Metering & Grid functionalities for water account for 17% of the total, while for gas and thermal energy, values are 5% and 1% respectively. In particular, smart water grids and meters are essential for conserving water, detecting leaks, and ensuring the

sustainable use of this vital resource. The same idea can be applied on gas and thermal energy.

Overall, the chart reveals a comprehensive approach to smart metering and grid functionalities, with a strong emphasis on electricity and renewable energy.

3.1.4. Number of projects per year for each application field

Through this indicator, it was possible to examine the annual trends from 2015 to 2024 of smart city projects across each category of application field in Europe. The dataset used is the merged database of 1339 projects. These trends can be observed in *Figures 16, 17, 18, 19*.

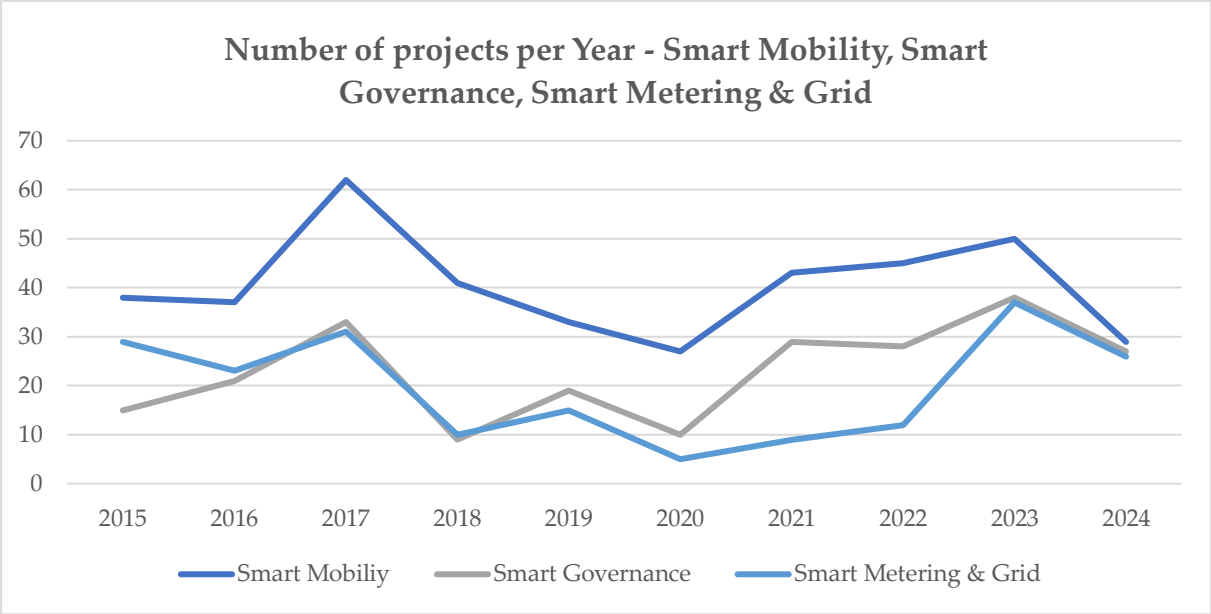


Figure 16: Number of projects per year – Smart Mobility, Smart Governance, Smart Metering & Grid

Figure 16 displays the trends of the three application fields with the highest number of projects, as previously defined. Focusing on Smart Mobility, there is a noticeable increasing trend that peaks in 2017, then declines to a minimum in 2020, heavily impacted by the pandemic. After the pandemic, the number of projects began to rise again, reaching another peak in 2023. Regarding Smart Governance and Smart Metering & Grid projects, the next highest in terms of project numbers at the European level, the trend patterns are similar and consistent with the ones described in *subsection 3.1.1*, even with different figures. Particularly concerning Smart Metering & Grid, the absolute peak was registered in 2023 with 37 projects after constantly increase from 2021. This is mainly due to many European Union co-funded projects like RESPONSE,

SPARCS, NEUTRALPATH, FLEXCHESS and ASCEND, aimed at building positive energy districts (PED). In fact, PEDs, in most of the cases, have the objective of introducing electric and thermal smart grids and integrating the use of photovoltaic panels. Clearly this shows a great interest of the EU in projects aimed at achieving an optimized management of the electricity by introducing renewable energy resources to reduce the carbon footprint. 2023 is also the absolute peak of Smart Governance projects with 38 projects spacing from introduction of digital twins to apps and platforms for citizen engagement in the urban planning process.

In *Figure 17*, the trends of three additional application fields are shown, all of which have a substantial number of projects. Concerning Smart Environmental Monitoring, it can be seen a fluctuating trend with a noticeable peak in 2023. In this field the use of sensors to gather information about pollution and meteorological conditions to plan in a better way corrective actions is crucial. For Smart Building, the greatest interest in this field was recorded in 2017 with more than 30 projects, followed by a continuous decline until 2021. In 2022, the number of projects in this field rebounded to 19 projects and then decreased again up to the present. For Smart Lighting, the year with the highest number of projects was 2018, decreasing continuously until nowadays.

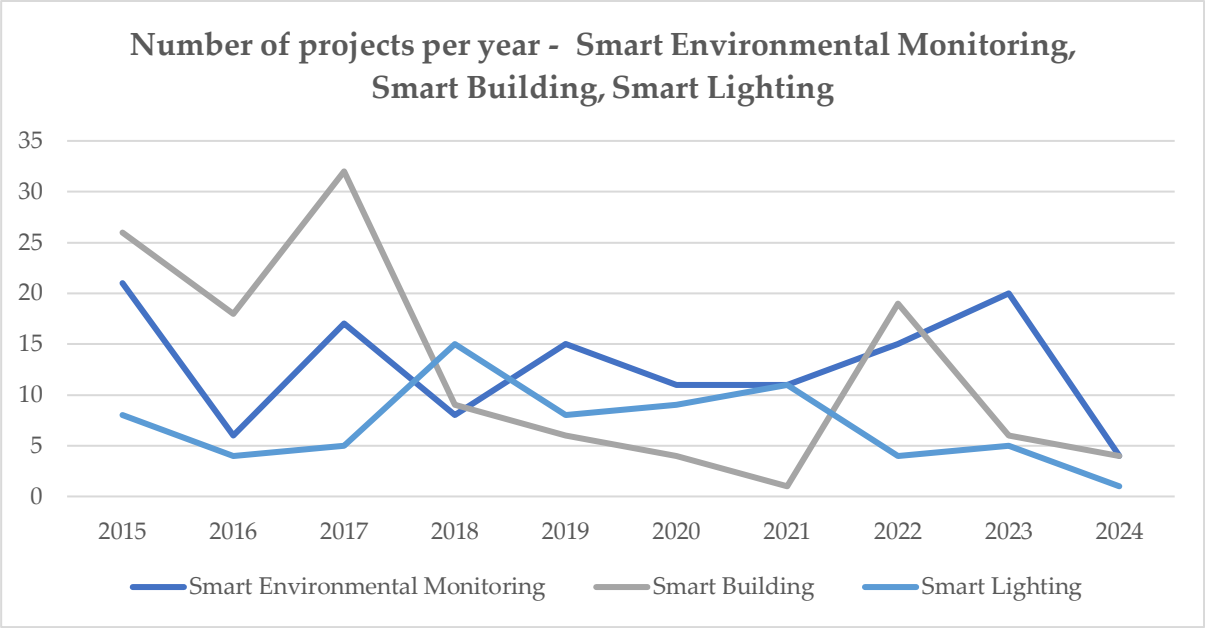


Figure 17: Number of projects per year – Smart Environmental Monitoring, Smart Building, Smart Lighting

In *Figure 18*, further trends can be observed. For Smart Waste Management, there was also growth in projects until 2018, followed by fluctuating results until the end of the analysis period. For eHealth, a significant peak was noted in 2023 with 23 projects, which then dropped to zero in 2024.

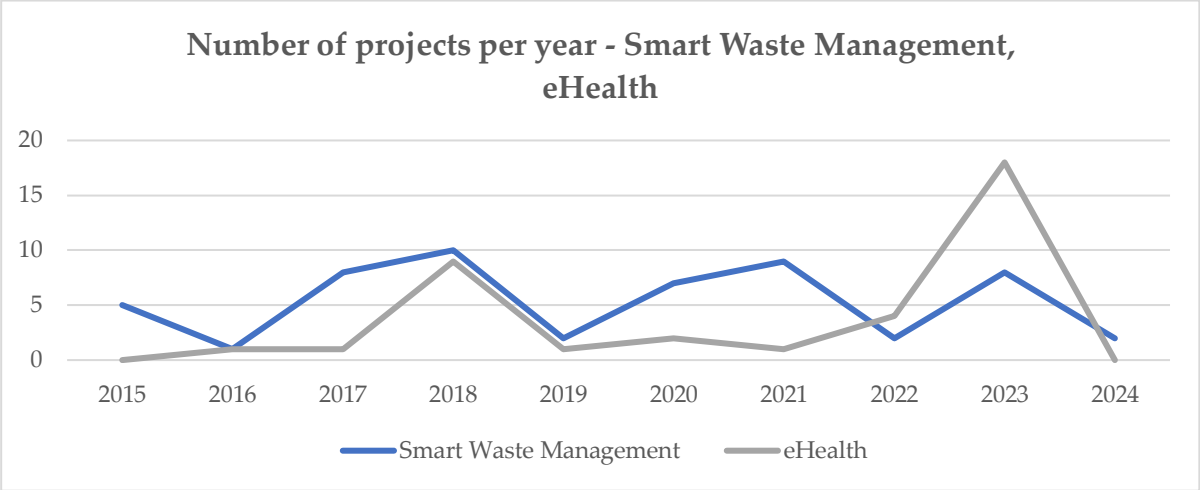


Figure 18: Number of projects per year –Smart Waste Management, eHealth

Finally, regarding the application fields with the fewest recorded projects shown in *Figure 19*, namely Smart Security, Smart Tourism, and Smart Agriculture, no particular trend is observed except for Smart Agriculture, which saw a surge in project numbers in 2024. This is due to a European initiative called AgriDataValue that involves 12 European countries, including Italy, with the goal of advancing smart agriculture through IoT sensors, drones, and satellites. The objectives are various and include smart irrigation, disease control, crop monitoring, and the integration of renewable energy.

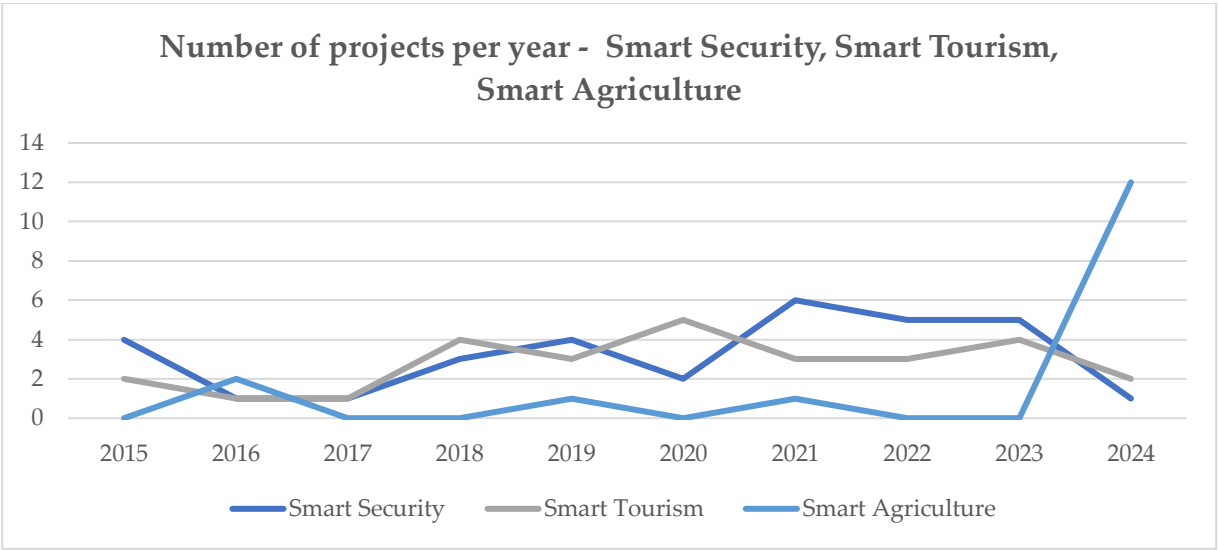


Figure 19: Number of projects per year – Smart Security, Smart Tourism, Smart Agriculture

3.1.4.1. Number of projects per year for each application field in Italy

Focusing on the Italian territory and its 389 projects, the trends are slightly different. *Figure 20* analyzes the trends for the application fields with the highest number of projects in Italy, namely Smart Mobility, Smart Governance, and Smart Metering & Grid. For Smart Mobility there was an increasing trend that touched its peak in 2018, then diminishing till 2022. Another noticeable peak was recorded in 2023, mainly due to two project initiatives: Green Ports and MaaS4Italy. Green Ports, implemented across various Italian ports, includes, for example, in La Spezia (one of the involved cities), the renewal of the vehicle fleet through the purchase of new electric cars, while in Livorno and Piombino, the acquisition of three hydrogen-powered boats was planned. Regarding Smart Metering & Grid, an initial high value was recorded in 2015 with 10 projects, including 3 in Milan, Brescia, and Bergamo for the installation of smart gas meters by A2A. The goal was to accurately monitor user consumption, resulting in greater awareness, remote management, and more precise billing. The highest value for this application field, after experiencing a decline in 2022, was seen in 2023 with 11 projects. In this year projects like "Smart Grid Valle d'Aosta" cited in the literature and once again "Green Ports" aimed at integrating renewable energy through photovoltaic panels in various Italian ports, gained relevance. In Trieste, the creation of a Port Grid was planned, allowing energy exchange within the port with consumption sites such as the public lighting system. Concerning Smart Environmental Monitoring, a growth in projects was recorded until 2019, likely also due to the climate neutrality goals proposed by the 2015 Paris Conference, then declining until 2021 due to COVID-19. Growth resumed, reaching a peak in 2022 thanks to projects in the Liguria region for monitoring the territory and preventing landslides and earthquakes in six different municipalities.

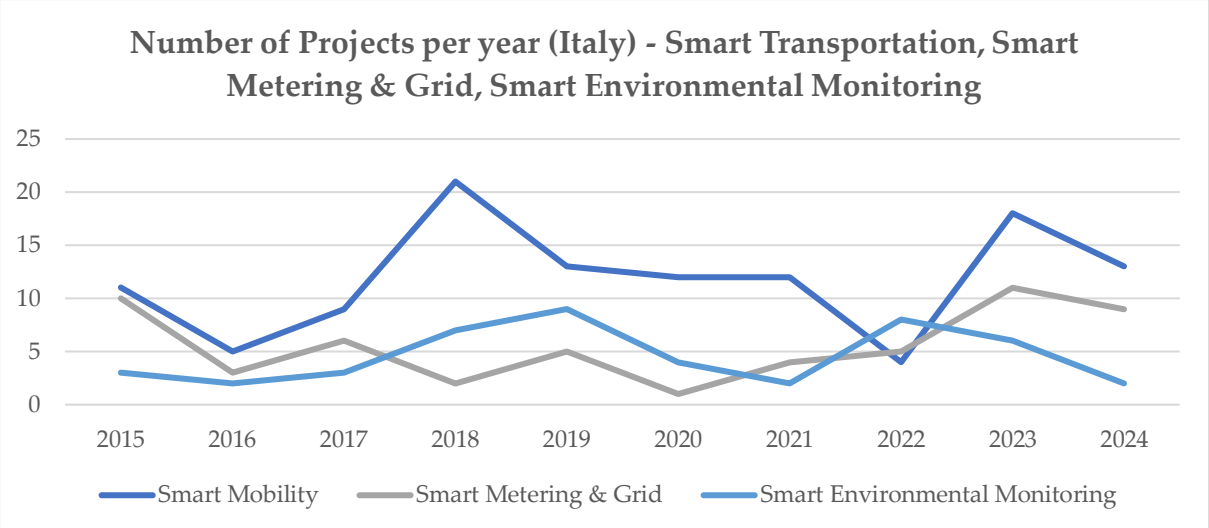


Figure 20: Number of projects per year (Italy) - Smart Mobility, Smart Metering & Grid, Smart Environmental Monitoring

In *Figure 21*, the annual trends of projects in the subsequent most important application fields are shown. Smart Lighting projects had positive trends that peaked in 2018, then declined up to the present day. For Smart Governance, the trend was generally upward until 2019, after which it decreased, likely due to COVID-19. However, from 2021 onwards, the number of projects in this field increased steadily, reaching a peak in 2024 with 8 projects. These include the digital twins of the city planned for Bologna and the Control Room in Florence, aimed at supporting urban planning with data.

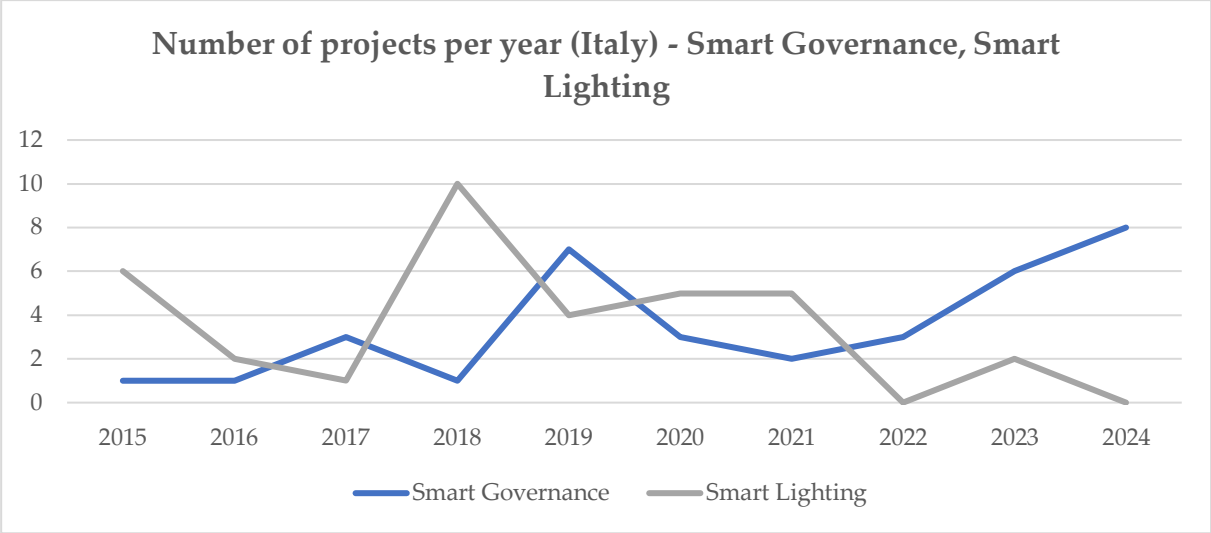


Figure 21: Number of projects per year (Italy) - Smart Governance, Smart Lighting

Regarding Smart Waste Management, *Figure 22* shows a fluctuating trend with a peak in 2018. After that, there was a noticeable peak in Smart Building projects in 2022 with 8 projects, demonstrating the impact of post-COVID European initiatives aimed at creating positive energy districts. For Smart Security, there are no significant trends.

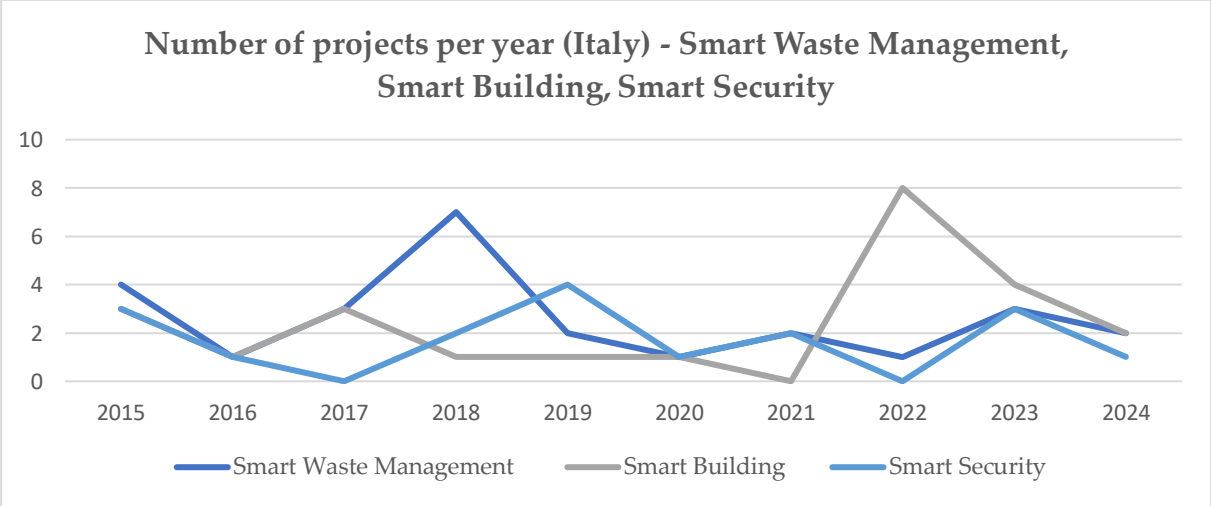


Figure 22: Number of projects per year (Italy) - Smart Waste Management, Smart Building, Smart Security

Finally, *Figure 23* shows the three application fields with the fewest projects in Italy. Smart Tourism initiatives average about 2 projects per year, which is still too few considering that Italy could leverage tourism much better. The eHealth field has an average of 1 project per year, with a noticeable increase in 2023 (4 projects), indicating growing interest in this area. Lastly, Smart Agriculture has almost always been negligible, showing it is a field that needs improvement. However, it is important to consider that this could be biased due to the difficulty in finding projects of this type.

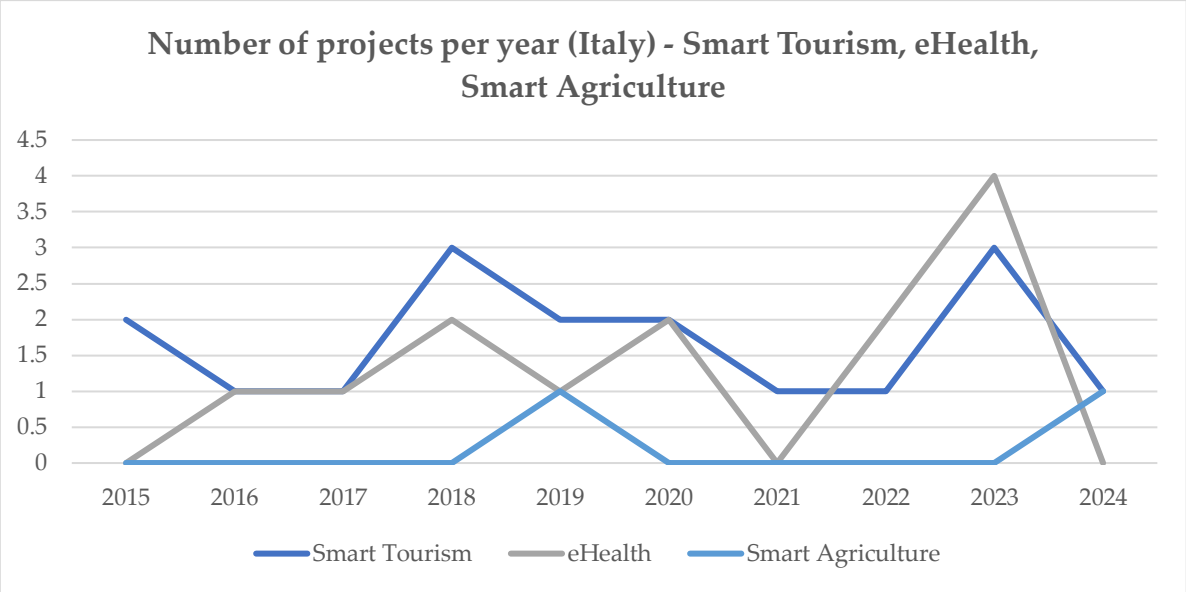


Figure 23: Number of projects per year (Italy) - Smart Tourism, eHealth, Smart Agriculture

3.1.5. Number of projects per nation

Considering the European context this indicator aims to map the situation of the projects divided by nations. In this way it is possible to understand which nations are more active in the smart city projects generation. The sample used comprises 1339 projects from 2015 to 2024 coming from the merged database. In *Figure 24* there is a panoramic view of the top 20 nations based on the number of projects. This choice derived from the fact that mapping all the nations listed in the database would have resulted in a confusional chart.

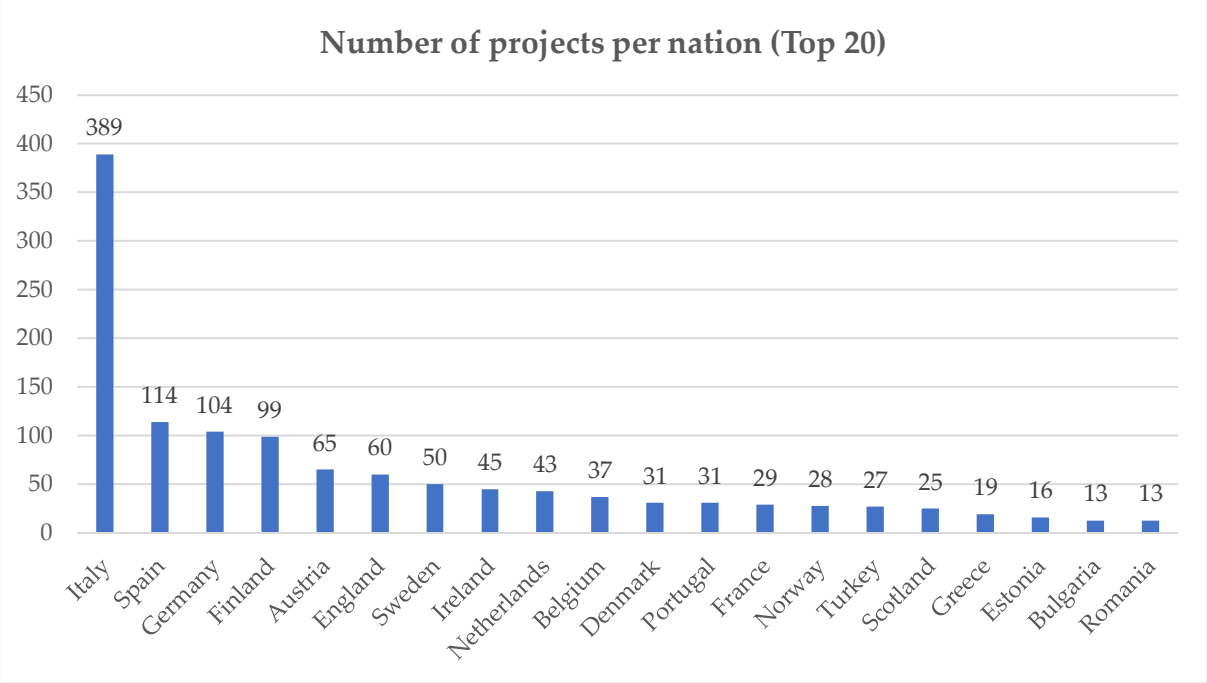


Figure 24: Number of projects per nation (Top 20)

The most striking observation is that Italy has a significantly higher number of projects compared to other countries even more than three times greater than the second-ranked country, Spain. This can be attributed to Italy being particularly active in smart city projects also thanks to great support given by the PNRR in recent years, but such a marked discrepancy with other countries indicates a distortion. This bias can be explained by two main reasons. Firstly, Italian smart city projects are more readily found on the web since the research was conducted in mother tongue. Secondly, a large number of projects comes from the Smart City Observatory's database of Polytechnic of Milan, which naturally has a greater focus on projects and trends within Italy. Additionally, many projects were sourced from the Observatory's Newsletter, which again has a focus on the Italian territory. For an easier visualization of the data related to the other countries, *Figure 25* has been introduced.

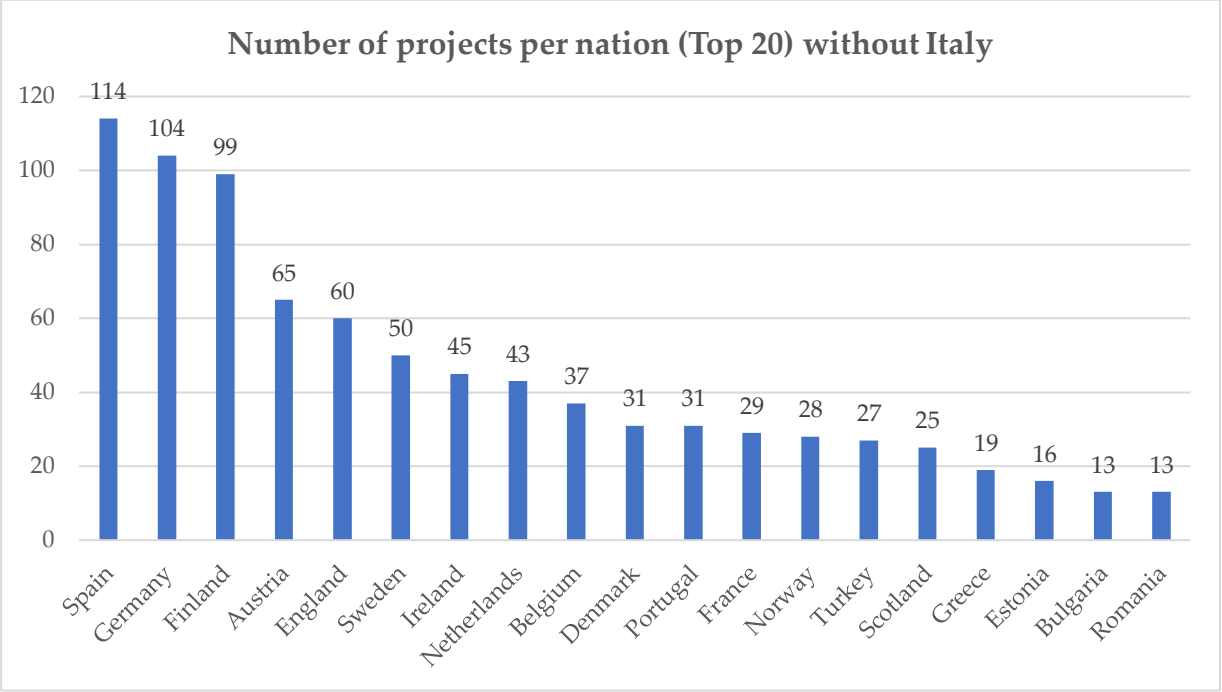


Figure 25: Number of projects per nation (Top 20) without Italy

Among the countries with the largest number of projects there are Spain, Germany, and Finland, each with around 100 projects, acting as pioneers. These countries can be considered leaders in the smart city context. Further down the list, countries like Austria, England, Sweden, Ireland, Netherlands present a moderate number of projects between 43 and 65, showing a great involvement in initiatives but not with the same level of the leader countries.

Belgium, Denmark, Portugal, France, Norway, Turkey, and Scotland have a number of projects ranging between 37 and 25. These countries, although out of the top 10, contribute significantly to the smart city landscape in Europe with prospects to increase their impact in future years. The lowest positions are occupied by Greece (19), Estonia (16), Bulgaria (13), and Romania (13), which have fewer projects, indicating potential areas for growth and future development. The distribution of this top 20 nations suggests that northern and western European countries are generally more active in smart city initiatives compared to eastern and southeastern European countries reflecting economic, political, or national priority differences. However, it is noticeable that Denmark and Norway, which are known for being active in numerous smart city projects, are not among the top positions. It would have been reasonable to expect them to have a number of projects comparable to Sweden and Finland. This discrepancy could be due to the difficulty in obtaining information about projects in these countries, as described in the methodology. Another surprising element is that France has only 29 projects. These observations could serve as starting points for future research.

3.1.5.1. Number of projects per Italian region

Focusing solely on the Italian territory, considering its 389 projects from 2015 to 2024, it is possible to identify which regions have the highest concentration of smart city projects. *Figure 26* illustrates the prevailing trend. Particularly notable is Lombardia, which stands out significantly in terms of the number of projects compared to other regions, reaching 82 projects. This data is coherent since this region is one of the wealthiest and most economically developed of Italy, resulting in availability of financial resources for innovative projects. Moreover, in Lombardia there is a strong presence of tech companies, research institutions and universities, all crucial to support the growth of smart city initiatives. Finally, this region is densely populated, and this translates in usual smart city challenges such as traffic congestion, pollution, energy and waste management. Other regions such as Lazio, Tuscany, and Emilia-Romagna also play an important role, with each reporting 38 and 35 projects respectively. A general observation reveals that there are typically more initiatives in Central and Northern Italy compared to Southern Italy.

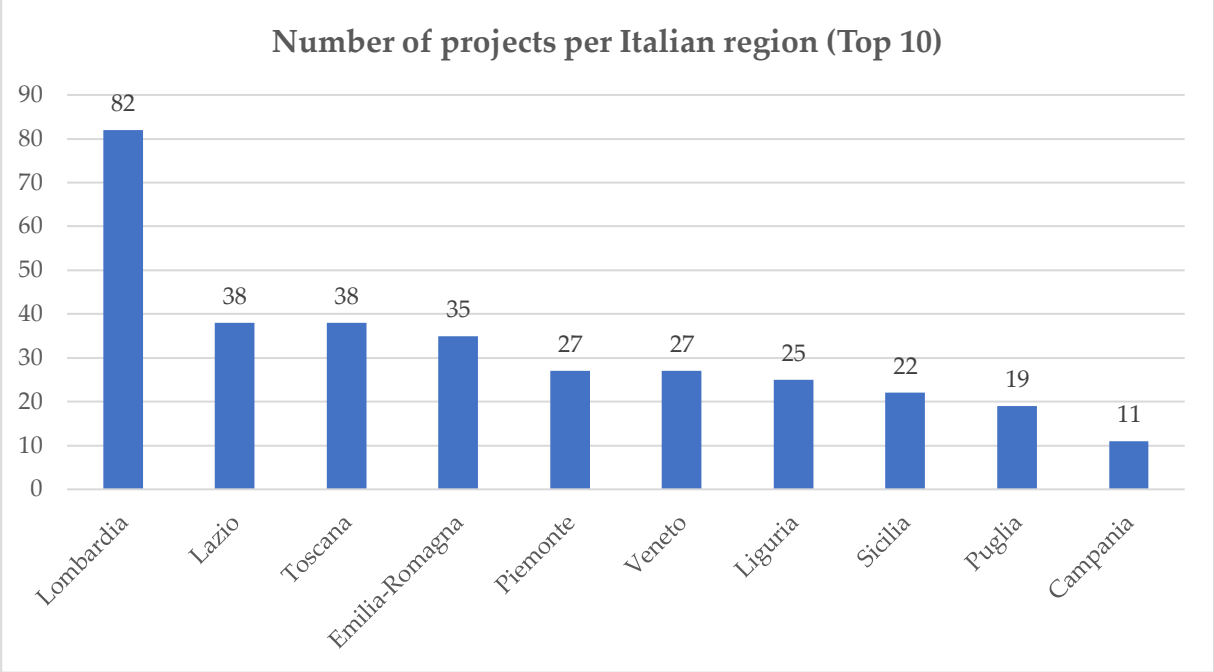


Figure 26: Number of projects per Italian region (Top 10)

3.1.6. Number of projects per application field for each nation

An interesting aspect to explore in the analysis is the type of projects, in terms of application fields, that other countries focus on most, aiming to understand their preferences and priorities. The sample used comprises 1339 projects from merging the database of the thesis and the one of the Smart City Observatory.

Germany shows the greatest interest in Smart Mobility projects with 43%, highlighting its emphasis on enhancing mobility and reducing urban congestion, likely reflecting the country's advanced automotive industry and commitment to innovative transport solutions. Sweden also focuses heavily on this area with 38%, suggesting a similar prioritization of efficient, sustainable transportation systems.

Austria shows a remarkable 31% investment in Smart Metering & Grid, indicating a strategic move towards upgrading their energy infrastructures and improving energy efficiency. This is substantially higher compared to other countries, demonstrating Austria's leading role in energy management within Europe.

In the realm of Smart Building, Austria again stands out with 30% of its smart city initiatives focused on this area, significantly higher than any other country in the dataset. This indicates a strong national focus on building sustainable and energy-efficient infrastructure, aligning with global sustainability trends.

Smart Environmental Monitoring is notably prioritized in Spain and England, each dedicating 16% of their efforts to this field, underscoring their focus on leveraging technology to fight environmental challenges and improve urban living conditions.

Interestingly, Finland's investment in eHealth is the highest at 8%, pointing to its emphasis on integrating technology in healthcare to enhance service delivery and patient care, a reflection of its advanced healthcare system and digital integration.

Sweden, despite its broad focus, allocates a significant 10% to Smart Waste Management, likely reflecting its environmental policies and commitment to sustainability.

Making a comparison between Italy and the other nations it is possible to say that generally all the countries have interest in Smart Mobility and Smart Metering & Grid projects. However, Italy dedicates 30% of its smart city efforts to Smart Mobility, aligning closely with countries like Austria and England but falling behind Germany and Sweden, which show a higher emphasis, at 43% and 40% respectively. This indicates Italy's commitment to improving urban mobility but suggests that other nations might be allocating more resources towards more extensive or advanced transportation projects.

In Smart Metering & Grid, Italy's focus at 15% matches Germany's but is significantly lower than Austria's 31%, indicating a strong but not leading position in energy management innovations compared to Austria, which appears to be at the forefront of integrating advanced energy solutions in Europe.

Italy also shows considerable investment in Smart Building and Smart Waste Management at 6% and 7%, respectively. While lower than Austria's leading 30% in Smart Building, it aligns more closely with the average focus across other nations, indicating a balanced approach towards sustainable infrastructure development. For

Smart Waste Management, Italy's investment is notable compared to countries like Germany and Finland, highlighting its commitment to sustainability and efficient waste handling.

Comparatively, Italy's engagement in Smart Environmental Monitoring and Smart Governance is somewhat lower at 12% and 8%, respectively, compared to Spain and England, where these fields are more prioritized. This could reflect different environmental priorities or governance strategies where Italy may focus less on these areas compared to its European counterparts.

In summary, Italy's smart city strategy demonstrates a solid commitment to mobility and energy management, with a reasonable focus on building sustainability and waste management, reflecting a broad but focused approach to leveraging technology for urban development.

3.1.7. Number of projects per city

Another key element of the analysis involves understanding which European cities have the highest number of projects, thus identifying those that can be considered the smartest. The sample is made up of 1339 from 2015 to 2024 and *Figure 27* depicts the top 20 cities by number of projects in the European geographic area.

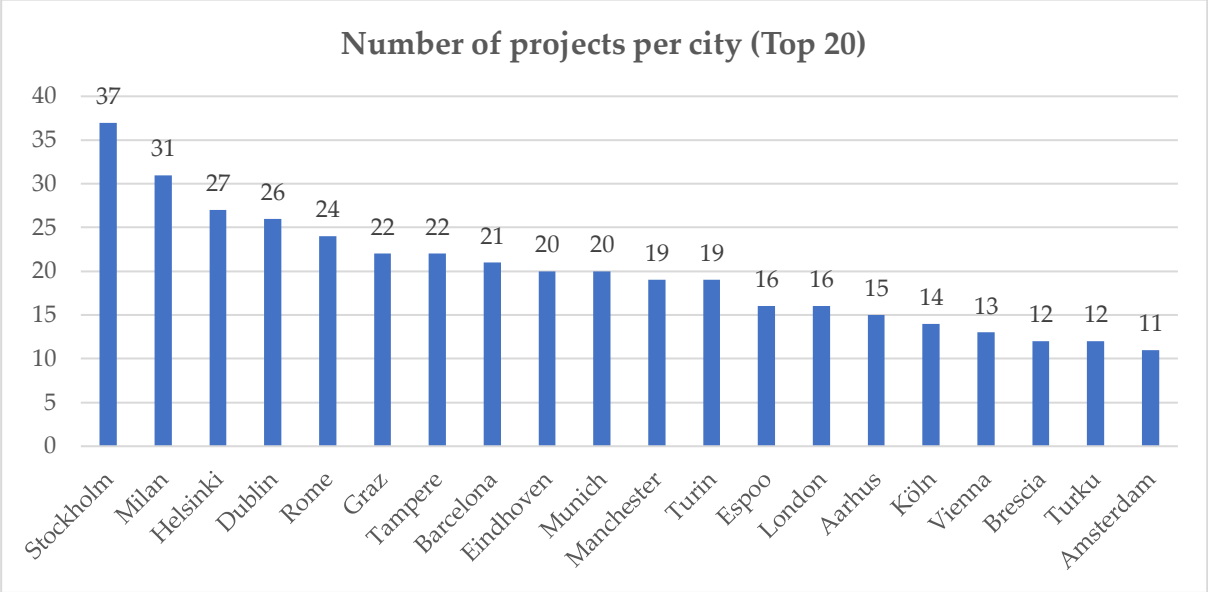


Figure 27: Number of projects per city (Top 20)

The smartest city in Europe is Stockholm with 37 projects, followed by Milan with 31 projects. Looking at the chart comprehensively, it is evident that many of the cities in this top 20 are located in Northern Europe, such as Stockholm, Helsinki, Tampere,

Espoo, Aarhus, and Turku. This highlights the pioneering role of Nordic countries like Sweden and Finland in technological and sustainability solutions. Another noteworthy point is the importance of Italy in the smart city context, with three Italian cities, Milan, Rome, Turin and Brescia, belonging to the list. Specifically, Rome and Milan appear in the top five positions, which might be influenced by the database's focus on Italian projects. Additionally, the United Kingdom plays a key role with cities like Dublin (Ireland), Manchester (England), and London (England) contributing significantly to the smart city landscape. Another city to consider is Barcelona, with 21 projects, which aligns with Spain's second place in the national ranking for the number of projects. The chart also features two German cities, Munich and Koln, with 20 and 14 projects respectively. Overall, the chart underscores the strong commitment of Northern European countries to innovation and sustainability, while also highlighting the significant contributions of Italy, UK, Spain and Germany to smart city development. Another insight derived from the chart is that many of these cities are metropolises, and even when they are of smaller size, they still serve as nerve centers for their respective countries. This suggests that the implementation of the smart city paradigm primarily begins in cities of this nature. For example, while Stockholm and Milan are large metropolitan hubs known for their advanced technology and sustainability efforts, smaller cities like Tampere and Espoo also play critical roles in their countries as centers for innovation and smart technology development. This pattern highlights the importance of both large and smaller cities in driving the smart city initiatives across Europe.

3.1.7.1. Number of projects per Italian city

Considering the 389 projects of Italy between 2015 and 2024, in *Figure 28* it is possible to see more in detail which are the most important cities in terms of number of projects in Italy, creating a top 10 ranking.

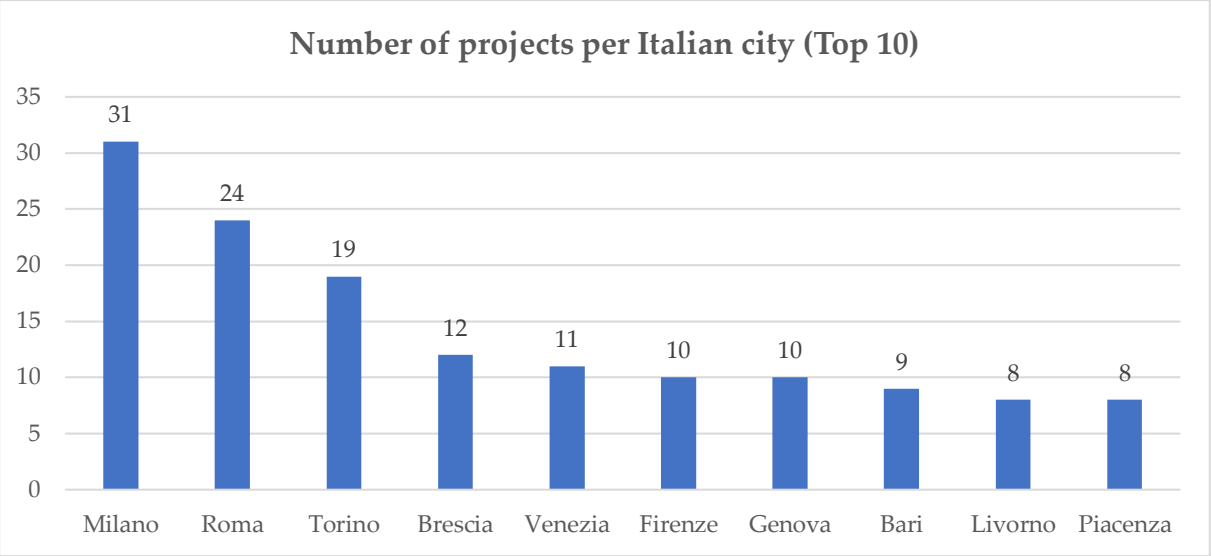


Figure 28: Number of projects per Italian city (Top 10)

Milan is the city in Italy with the highest number of projects, totaling 31. It has also been previously ranked as second in a European context. The second city is Rome with 24 projects, highlighting the capital's interest in investing in Smart City projects. The third city is Turin with 19 projects. Looking at the chart as a whole, it is evident that the top three cities have significantly more projects compared to the other cities in the top 10, which have around 10 projects each. The fact that Milan and Rome occupy the top two spots is not a coincidence, as they are the two most important and recognized cities in Italy: Milan for being the economic center of the country and Rome for being the capital and administrative center of Italy. Turin still is very important to be a technological and industrial center, similarly to Brescia. Moreover, the high number of smart city projects in Milan, Rome, and Turin is due to the need to address complex urban challenges arising from their high population. Indeed, these cities need innovative solutions to improve urban management, mobility, sustainability, and the quality of life for their residents. Generally, this top 10 list includes cities primarily from Northern and Central Italy, with Bari, in eighth place, being the only city from Southern Italy. Another notable element is that all the cities in this ranking can be considered pivotal centers both economically and culturally in Italy.

3.1.8. Number of projects per application field for each city

Considering the three most active European cities in terms of smart city projects, excluding Milan and Rome since they will be discussed in detail later in the Italian analysis, it is interesting to understand what types of projects are more commonly implemented. The cities in question are Stockholm, Helsinki, and Dublin.

The first city, Stockholm, the capital of Sweden, has a total of 37 projects, which represent almost 75% of the total projects found in the country. Stockholm places significant focus on Mobility projects, with 16 projects specifically targeting traffic monitoring, electric vehicle sharing, and Mobility as a Service platforms for public transportation. These projects were primarily developed between 2016 and 2018, with a particular emphasis in 2017.

In Helsinki, the highest number of projects are in the fields of Smart Governance and Smart Mobility, with 8 and 7 projects respectively. Smart Governance initiatives include the creation of public digital platforms, digital twins, and citizen co-participation solutions. Meanwhile, Smart Mobility in Helsinki focuses on micromobility solutions, traffic monitoring, and optimizing last-mile logistics.

Regarding Dublin, the majority of projects are in Smart Environmental Monitoring, with 9 projects implemented from 2015 to 2023. These projects focus on monitoring air and water quality, as well as river water levels to respond quickly to severe weather events that cause flooding. Dublin has also implemented Smart Mobility solutions, with 6 projects mainly aimed at managing public transport passenger flow and monitoring traffic conditions. Additionally, innovative solutions like delivery drones were tested in 2023.

In summary, Stockholm is heavily invested in Smart Mobility, Helsinki balances between Smart Governance and Mobility, and Dublin focuses on Environmental Monitoring with notable efforts in Smart Mobility as well.

3.1.8.1. Number of projects per application field for each Italian city

Considering the sample of the 389 projects in the Italian territory between 2015 and 2024 represented in the merged database, Milan has been involved in a wide range of smart city projects. Of the 31 projects in the city, the most significant fields are Smart Metering & Grid and Smart Governance, with 6 projects each. Notably, interventions were made to digitalize the supply of electricity, gas, and water through the introduction of smart meters in each sector. In 2023, tests were conducted to scan the urban area using Lidar, providing data to support decision-making. Smart Environmental Monitoring and Smart Mobility projects have also remained important,

with 4 projects each. One particularly interesting project scheduled for 2024 involves the purchase of a fleet of electric buses.

Rome, with 24 projects, has shown a strong focus on Smart Mobility, with 11 initiatives including MaaS platforms, autonomous vehicle testing, and sharing solutions. Significant attention has also been given to Smart Metering & Grid, with 5 projects, including the creation of a digital twin of the electrical grid planned for 2024.

Turin presents a more balanced situation with 19 projects. The main areas of intervention are Smart Mobility, with 11 projects, and Smart Building with 4 projects, representing the most significant initiatives in numerical terms.

3.2. Investments analysis

The analysis of funds aims to explore in detail how projects are financed and the amount of money they receive. It examines trends over time and across different regions and identifies the fields that receive the most funding. Similar to the previous set of indicators, the funding indicators will first analyze the European context and then focus on the Italian context when deemed useful.

Most of the following analyses used a merger of the Smart City Observatory' database and the one created specifically for this thesis, covering the period from 2015 to 2024, with a total of 1339 projects. This approach provides a more comprehensive temporal view. However, some analyses were conducted solely on the new database created for the thesis because it contains additional columns that allowed for more targeted analyses regarding EU programmes and funds. In such cases, this is specified for each individual indicator and comprises only 472 projects between 2021 and 2024.

3.2.1. Number of projects per investment typology

An essential aspect of comprehensively analyzing smart city projects is understanding the distribution of initiatives across public, private, and public-private partnership sectors. Considering 1339 projects from 2015 to 2024, as observed in *Figure 29*, the majority of projects, specifically 65% of the total, are funded through public sources. These funds come from municipal, regional, national, and even supranational levels, such as the European Union. This significant public investment highlights a strong commitment by public entities to innovate urban infrastructures, enhance citizens' quality of life, reduce pollution, and achieve the United Nations' Sustainable Development Goals. A key factor explaining the high percentage of publicly funded projects is that EU-funded projects are categorized as public in the database, even if a small portion of the funding comes from private entities.

In contrast, initiatives solely funded by the private sector account for only 6% of the total projects since smart city initiatives are quite costly and for a private actor to sustain alone the investment is very risky. Finally, 29% of the projects are financed through public-private partnerships (PPPs), a model that is gaining increasing attention as it enables the sharing of both risks and benefits between the public and private sectors.

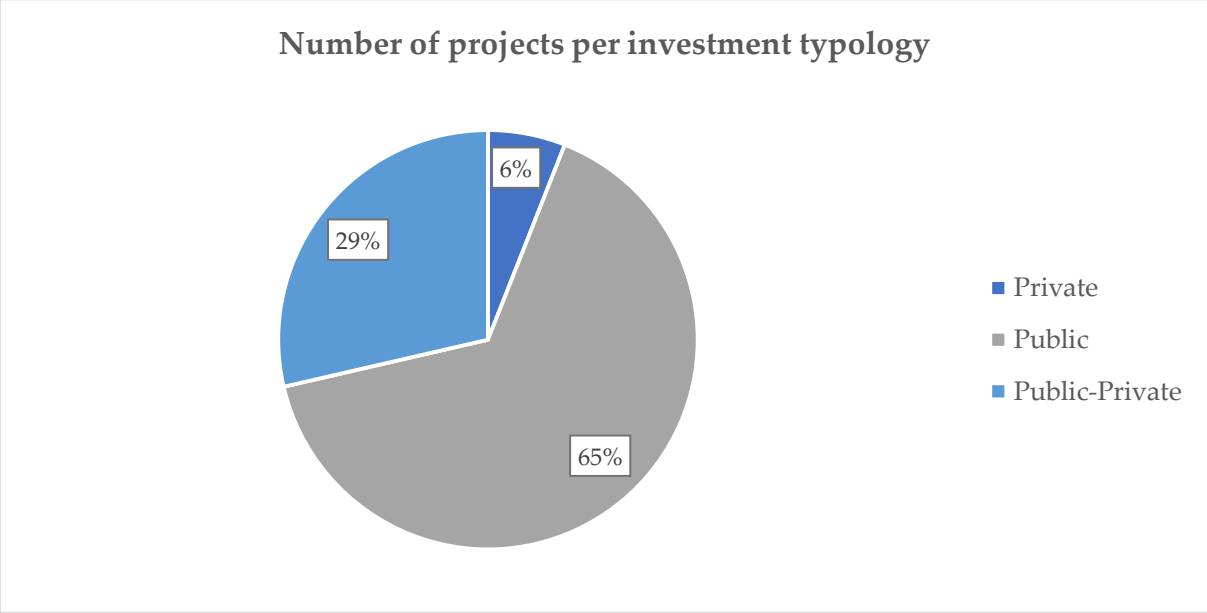


Figure 29: Number of projects per investment typology

3.2.1.1. Number of projects per investment typology in Italy

Considering 389 projects in Italian territory from 2015 to 2024, in *Figure 30*, the proportions of the number of projects by funding type show that, similarly to the European context, Italy also has a predominance of projects financed through the public sector (60%), followed by public-private partnerships (28%) and then the private sector (12%).

What stands out in the Italian context is that the percentages for public funding are almost the same as in Europe, but there is a higher involvement of the private sector in smart city projects, registering a value that is the double compared to the 6% recorded in Europe.

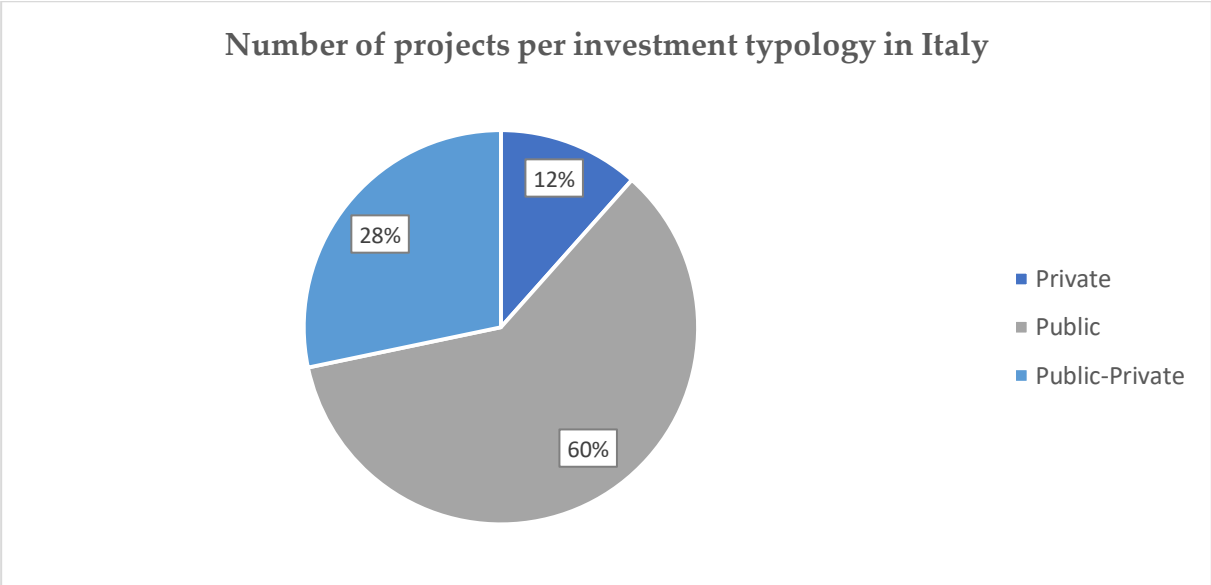


Figure 30: Number of projects per investment typology in Italy

3.2.2. Total cost per investment typology

Once the distribution of the number of projects for each type of investment is defined, it becomes interesting to understand the amount of money allocated by each sector. For this kind of analysis, it is important to note that the data about "Total Cost" is available only for 767 projects of the 1339 projects registered in the merged database (57% of the total) between 2015 and 2024.

In *Figure 31*, considering a total cost of 14.3 billion for the sum of the three categories, it is evident that the total costs of projects financed through public-private partnerships are significantly higher compared to those from the public and private sectors. Although there are many more projects in terms of number concerning the public sector alone, it is reasonable that the total amount for partnerships could be

higher. However, the fact that it is more than 3 times higher suggests the presence of a bias.

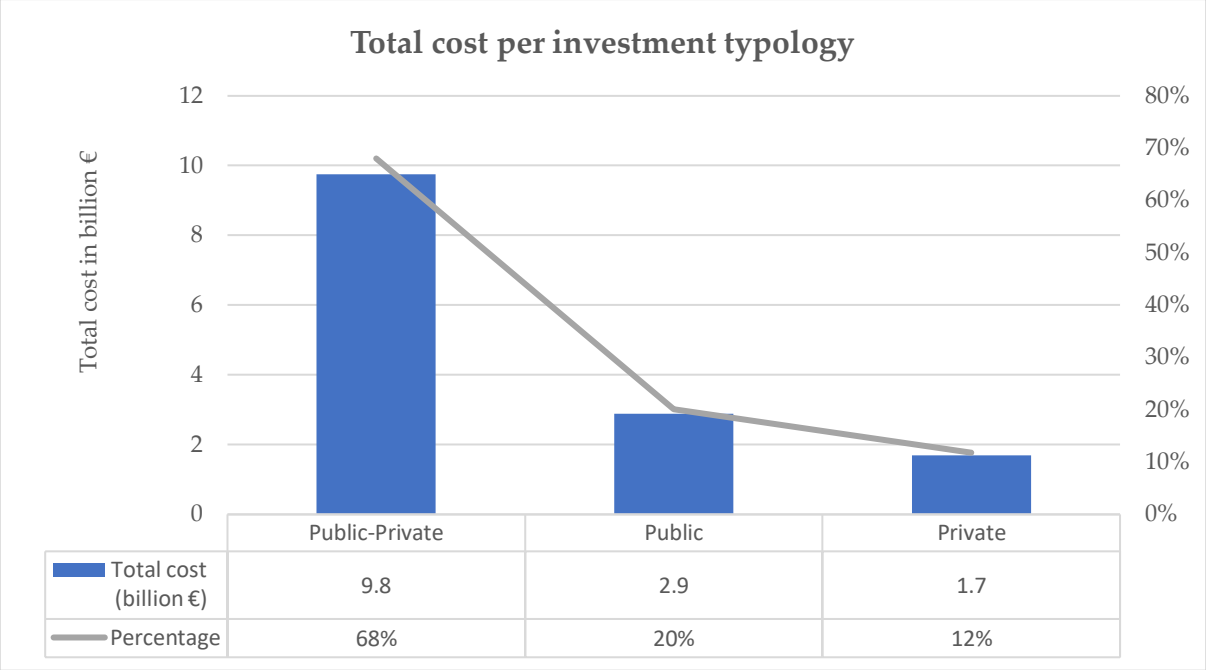


Figure 31: Total cost per investment typology

In fact the value of public private-partnership is mainly due to the project "The Ellinikon" in Athens. It is clearly an outlier since it totals €8.5 billion alone.

In dept analysis, The Ellinikon – Athens

Estimated to cost 8.5 billion euros, the project is set to transform the former Ellinikon International Airport site in Athens, which has been inactive since 2001. Managed by Lamda Development, a Greek real estate company, it will start in 2024 and aims for completion by 2037. Although the Greek government will assist in coordinating this extensive project, it will not provide direct financial support. Lamda Development has secured 2.5 billion euros in financing for the initial phase, comprising approximately €1 billion from bank loans, €600 million from an equity capital increase, €200 million from bond issuance, and €800 million from pre-selling parts of the development, including residential units, shopping centers, and other facilities. For example, the European Bank for Reconstruction and Development (EBRD) has invested €42.7 million euros in the project through Lamda's equity and bond issues, supporting the project's sustainable initiatives and contributing to a new metropolitan identity for Athens. Lamda will partner with the Saudi-owned Olayan Group and the US-based Brook Lane Capital to develop additional residential buildings and hotels. Hard Rock will construct an integrated resort and casino, while Mandarin Oriental plans to open a hotel by 2027. The Greek real estate company also intends to form further joint ventures, seeking both

international and local expertise. The Ellinikon project will incorporate various smart city technologies, including sensors, AI, IoT-based water and waste management systems, high-speed fiber optics, 5G coverage, smart parking solutions, and sustainable mobility options such as bikes, e-bikes, and scooters. The buildings will be designed for maximum energy efficiency, and the project will feature Europe's largest coastal park, with 31,000 new trees and a 2 million square meter space. This initiative promotes the use of renewable energy and aims for a zero-carbon footprint, creating a mini-city called Little Athens, where every location is reachable within 15 minutes.

Once excluded the value of "The Ellinikon" project, which will not be considered in the analyses of this chapter, and considering 766 projects as available dataset, the results in *Figure 32* show that Italian investments, amounting to approximately €4.6 billion, represent 78% of the total spending of €5.9 billion on smart city projects in Europe. While Italy undoubtedly plays a crucial role in the European smart city landscape, this clearly indicates the presence of a significant bias, probably related to the easiness of finding information about costs of Italian projects.

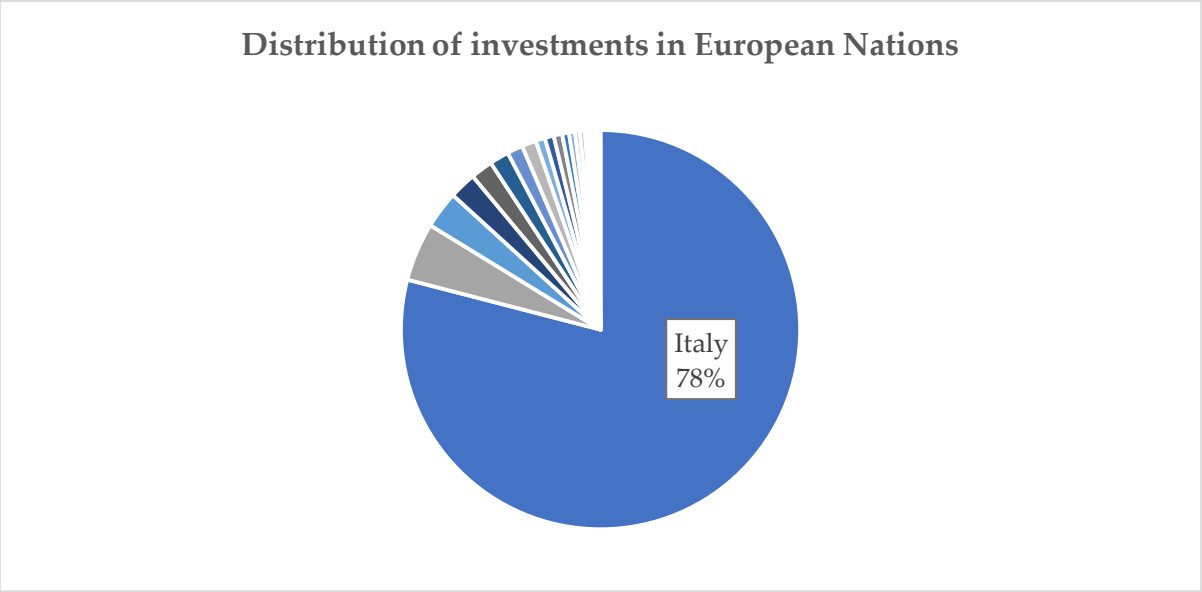


Figure 32: Distribution of investments in European Nations

To avoid this kind of bias, the analyses of investments will be conducted separately for Europe and Italy. In particular, for the European level analyses, the value of Italian investments will be excluded from the total to ensure a more balanced and accurate representation of the European context.

In *Figure 33*, the distribution of total costs across the three sectors in Europe is displayed. This analysis excludes the outlier project "The Ellinikon" and the Italian investment value of €4.6 billion, remaining with a total of €1.3 billion for the entire European landscape. In particular the dataset, as said before, has 766 available data about investment, from which 179 come from Italian projects. As a consequence, for this analysis 587 values will be considered. The chart clearly shows a significant prevalence of public funds (68%), primarily due to numerous initiatives from European Union bodies aimed at promoting innovation among member states. Public entities are particularly interested in funding smart city projects to enhance public services, reduce carbon emissions, and increase energy efficiency, thus benefiting the entire community.

Private investments account for only 1% of the total, highlighting the difficulties private entities face in taking on the risks associated with smart city projects, which involve high initial costs and long investment recovery periods. In contrast, public-private partnerships (PPPs) account for 32% of the total investments, indicating that combining resources and sharing risks between the public and private sectors can be an effective approach.

In summary, the funding distribution reflects the different motivations and strategies between the public and private sectors. Public entities focus on community welfare and service improvements, while private investors are attracted to profit and operational optimization opportunities. Public-private partnerships offer a balanced approach, enabling ambitious projects to be realized through shared risks and benefits.

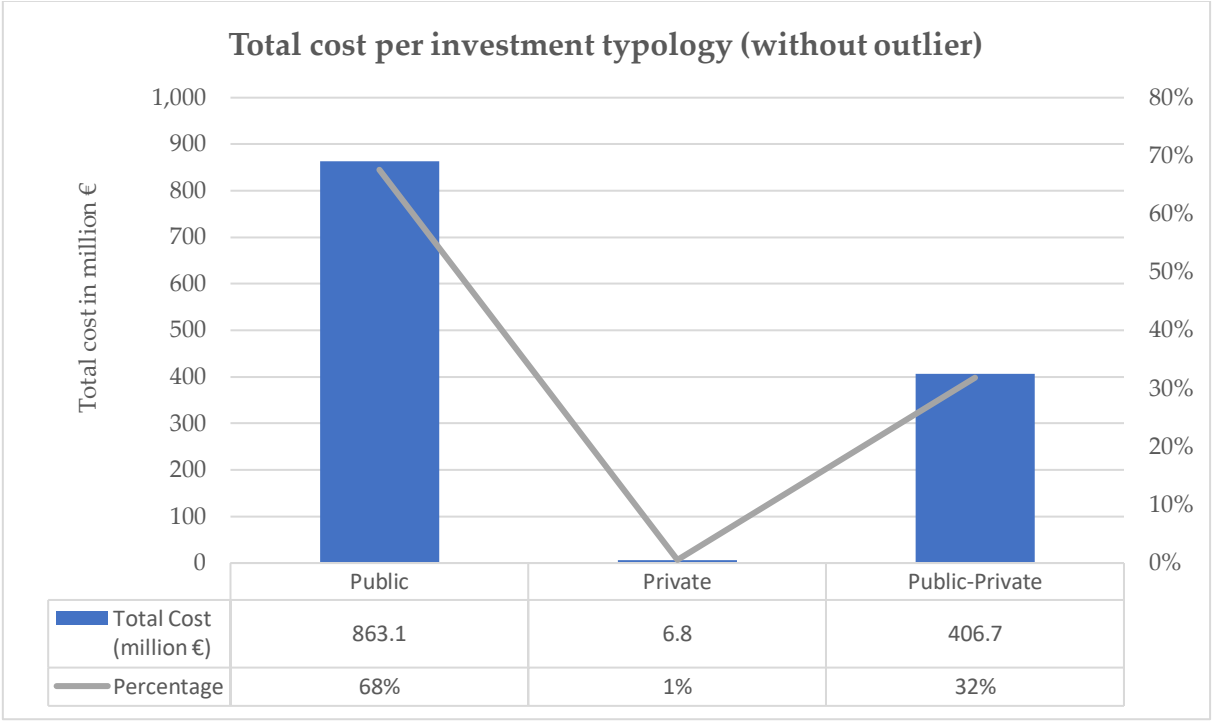


Figure 33: Total cost per investment typology (without outlier)

3.2.2.1. Total cost per investment typology in Italy

As previously mentioned, the separate analysis for Italy shows significantly different values compared to the European level analysis, with project costs amounting to €4.6 billion. This results in a completely different scale of investment. The available investment cost accounts for 179 projects in Italian territory from 2015 to 2014.

Figure 34 shows that, once again, the public sector has allocated the most funds for projects, consistent with the high number of projects it finances. However, compared to the European context, Italy shows a more balanced distribution between the public and private sectors, showing respectively 44% and 37% allocated.

Despite having the lowest number of projects, only 12% of the total in Italy, private investments achieve considerable value, ranking second among funding sources. This is due to the fact that private companies see smart city projects as opportunities to gain substantial economic returns and optimize their operations. For instance, a smart metering project can lead to monitoring and optimizing energy consumption, reducing waste and operational costs. Additionally, accurate and timely billing can lower management costs, enable more competitive pricing, attract new customers, and increase the satisfaction of existing ones.

For PPPs, the value stands at around 19%, which is still relatively low, especially if compared to the 43% registered in Europe. This indicates that Italy could benefit more from increasing these types of collaborations to harness their potential advantages.

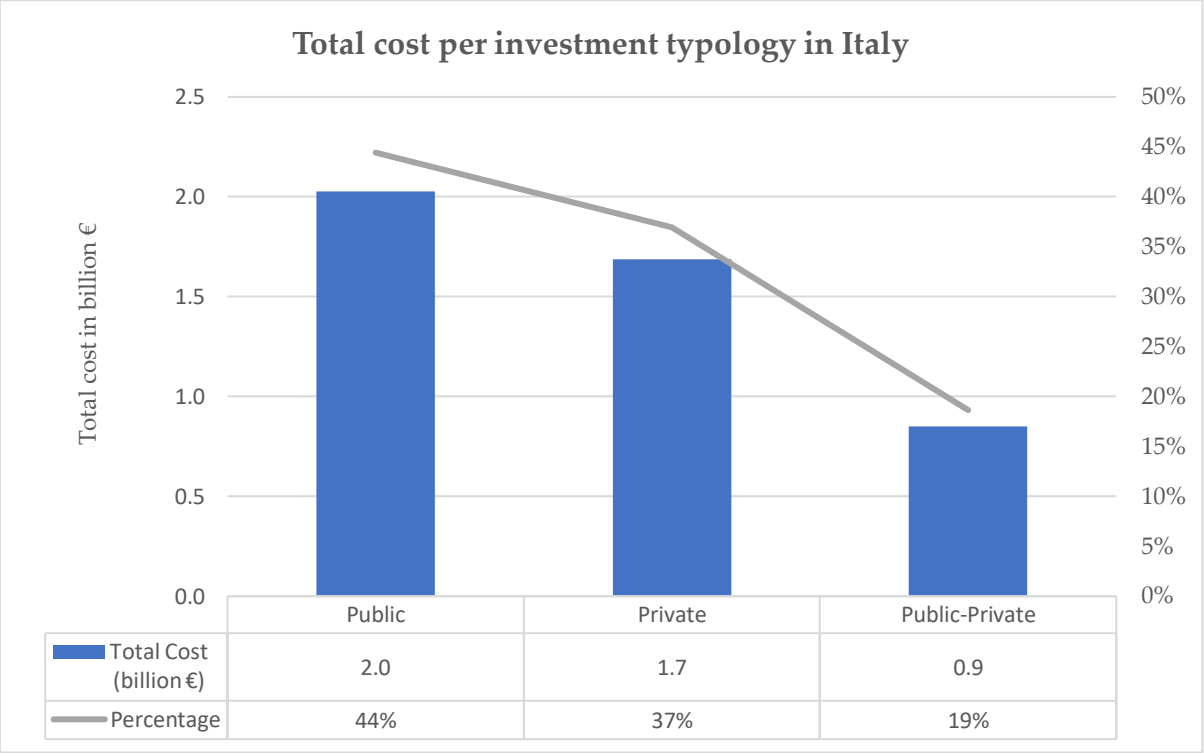
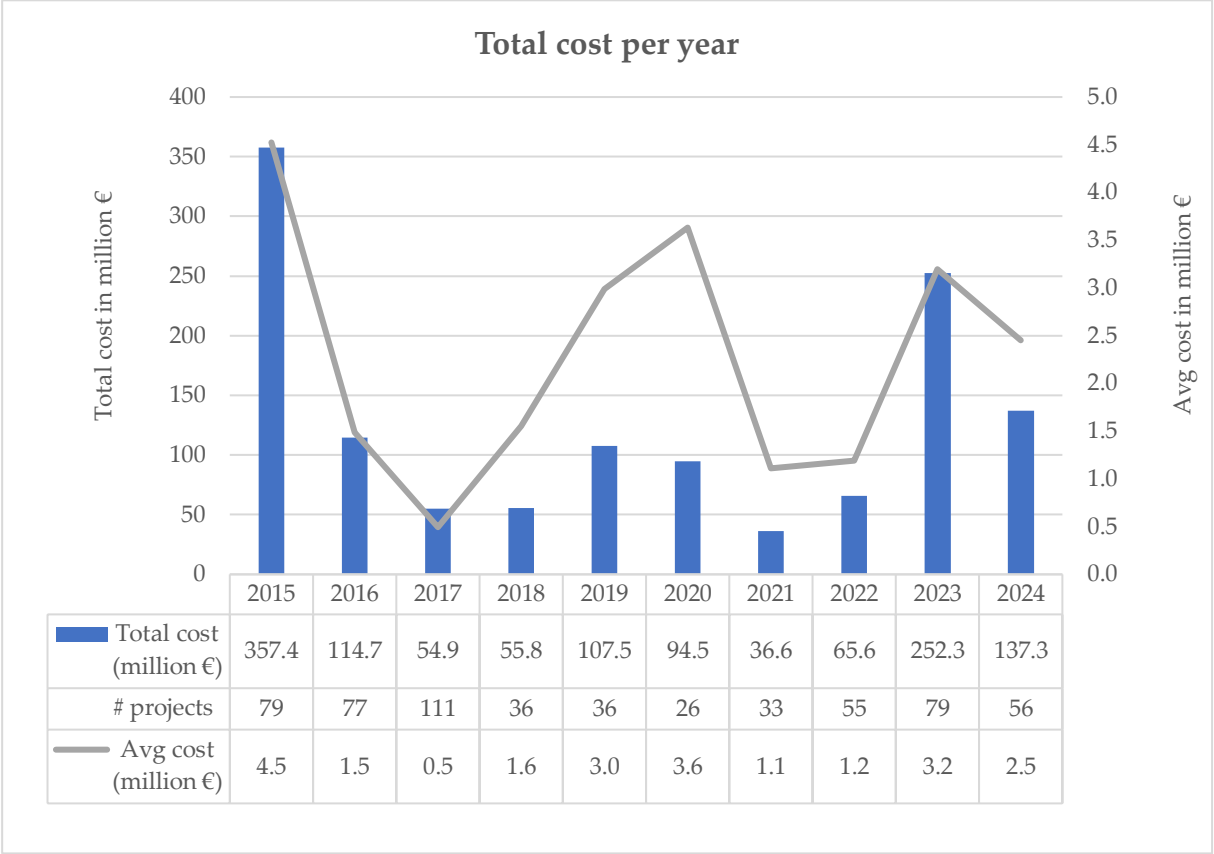


Figure 34: Total cost per investment typology in Italy

3.2.3. Total cost per year

The indicator aims to understand the trend of investment allocation from 2015 to 2024 to identify significant trends in Europe. This data relates to 588 values of investment available totaling €1.3 billion. As shown in *Figure 35*, the investment trend for the European Union is quite different from what might be expected based on the number of projects. This discrepancy is due to the difficulty in obtaining a substantial number of investment data, particularly at the European level.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Total cost (million €)	357.4	114.7	54.9	55.8	107.5	94.5	36.6	65.6	252.3	137.3
# projects	79	77	111	36	36	26	33	55	79	56
Avg cost (million €)	4.5	1.5	0.5	1.6	3.0	3.6	1.1	1.2	3.2	2.5

Figure 35: Total cost per year

To provide a comprehensive description of the total cost trend over this period, the graph has been enriched with information regarding the number of projects and their average annual cost. The average annual cost of projects is calculated as Total Cost divided by the Number of Projects for each year. Observing the total cost over the years, it is evident that it has fluctuated significantly.

2015 represented a year with particularly high total costs (€357.4 million), the highest of the time span considered, due to a high number of projects (79) with an average cost per project that was also the highest in the analyzed period (€4.5 million). This could be reconducted both at the Paris Agreement of 2015 and the United Nations' SDGs defined in that year that aroused interest in finding solutions to be more sustainable.

In 2016, even with a similar number of projects as in 2015 (77), the total cost drastically reduced to €114.7 million, thanks to a much lower average cost per project (€1.5 million).

In 2017, the total cost was the lowest (€54.9 million), despite having the highest number of projects (111), indicating an average cost of project which was the lowest of the period amounting to only €0.5 million. However, from 2017 to 2019, the total cost almost doubled, reaching €107.5 million, even though the number of projects decreased by almost three times, from 111 to 36 projects, showing a particularly high average cost of about €3 million per project.

2020 saw a drop in the number of projects to 26, justifiable by Covid-19, but maintained a high average project cost reflecting complex and high-value initiatives, keeping the total cost similar to the previous year. From 2021 to 2023, the total cost of projects increased nearly sevenfold, from €36.6 million to €252.3 million, due to both an increase in the number of projects and an increase in the average cost per project, which reached €3.2 million. It is clear that there was a recovery after the pandemic, showing both increased interest in smart city projects and indicating large-scale and complex projects.

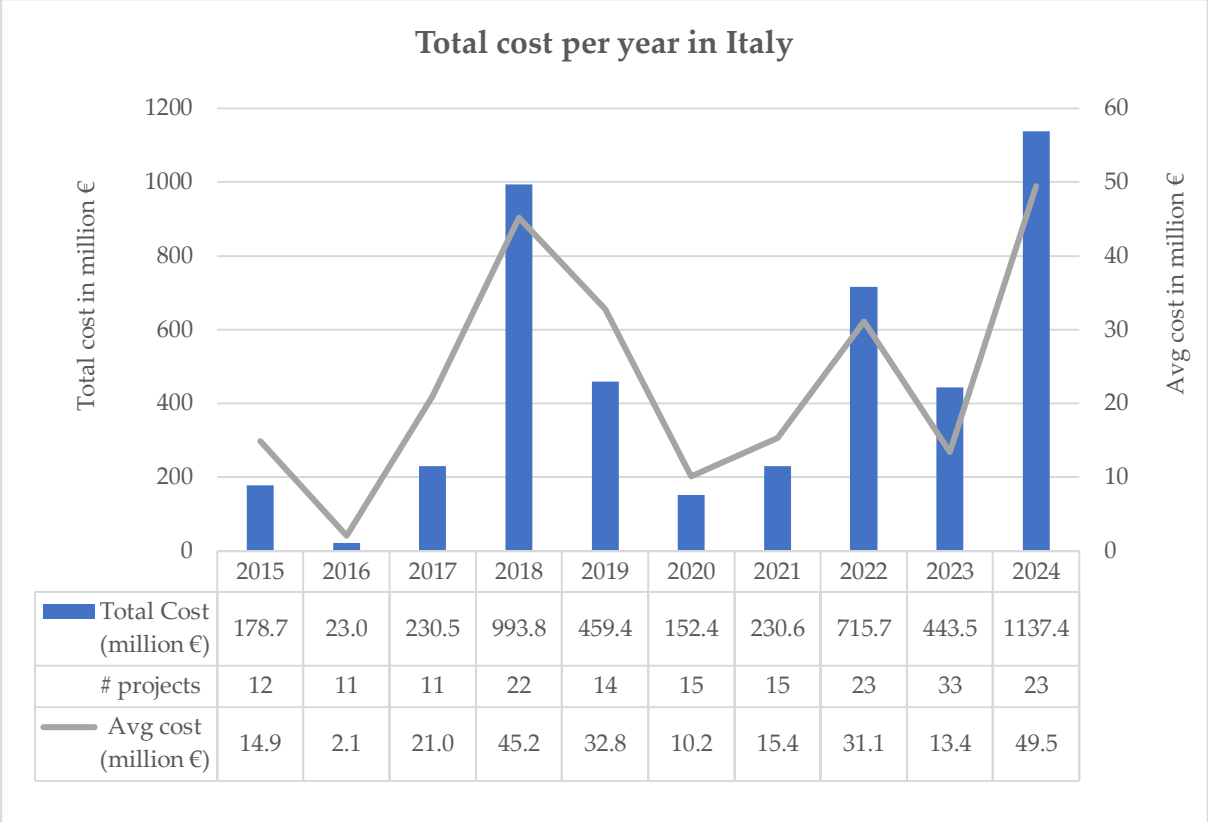
The most recent year recorded is 2024, with a total cost of €137.3 million and an average cost per project of €2.5 million. Considering that the data collection stopped only in April 2024, it clearly indicates that the total cost could reach even higher values than in 2023, with slightly lower average costs, indicating continued interest in large-scale projects but with lower average costs achieved through technological maturity.

In general, it can be said that the years with high total costs (2015, 2023, 2024) were often associated with a high average cost per project and/or a significant number of projects. Years with low total costs tend to have lower average costs per project or a larger number of smaller projects, indicating variations in investment strategies and the scale of projects over time.

3.2.3.1. Total cost per year in Italy

Regarding Italy, given the extensive data available on investments, it can be expected a trend similar to the number of projects per year. The sample used for this analysis includes 179 total investment cost values, amounting to approximately €4.6 billion. This figure is significantly higher than the combined investment total of all other European nations which was 1.3 billion. Consequently, it was decided to analyze Italy's total project investment costs per year separately to avoid biasing the overall European analysis.

Thanks to the large availability of data, as can be seen in *Figure 36*, the overall investment trend closely follows the one of the annual number of projects in Italy, as expected.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Total Cost (million €)	178.7	23.0	230.5	993.8	459.4	152.4	230.6	715.7	443.5	1137.4
# projects	12	11	11	22	14	15	15	23	33	23
Avg cost (million €)	14.9	2.1	21.0	45.2	32.8	10.2	15.4	31.1	13.4	49.5

Figure 36: Total cost per year in Italy

Looking at the graph, it is notable that there was a rapid increase in investments from 2016 to 2018, with the total cost rising from €23 million to around €1 billion, and the number of projects doubling from 11 to 22. Additionally, the average project cost increased more than 20 times, indicating a focus on implementing very large-scale projects. This trend reflects Italy's commitment to climate neutrality goals following the 2015 Paris Conference and the United Nations' SDGs.

However, this growth declined until 2020, with the total cost dropping to €152 million. This decrease was due to both a reduction in the number of projects and a decrease in the average cost per project, which fell to €10.2 million. This downward trend is primarily attributed to the impact of the COVID-19 pandemic which shifted interest in fighting the disease.

After 2020, investments began to rise again, driven by the recovery from the pandemic and the introduction of National Resilience and Recovery Plans. The number of projects increased, reaching 33 in 2023, with a total cost of €443.5 million. Although the total cost in 2023 was lower compared to 2022 (€715 million), the number of projects

increased. The lower total investment value was related to a significant drop in the average project cost, which decreased from €31.1 million in 2022 to €13.4 million in 2023. This could be explained by an interest in projects of smaller size.

An interesting observation in 2024 shows a decrease in the number of projects compared to 2023, but a substantial increase in allocated funds, reaching the highest investment value within the period, despite the data being collected only until April 2024. The average investment per project in this time span was €49.5 million, the highest in the entire period analyzed. This indicates a strong and growing interest in smart city projects, demonstrating a combination of technological maturity and a greater willingness to invest in larger projects with higher financial requirements.

3.2.4. Total cost per application field

Considering the European landscape, it is interesting to understand which application fields have required the most significant financial expenditure for project implementation. In this case it is not necessary to make a distinction between Italy and the rest of Europe since the goal of the analysis is to understand which kind of projects received the highest amount of fund. For this reason all the total cost data available were used, comprising Italy, and excluding only "The Ellinikon" project for a total of 66 data available (€5.9 billion). *Figure 37* shows the total cost for each of the application fields defined in the literature chapter.

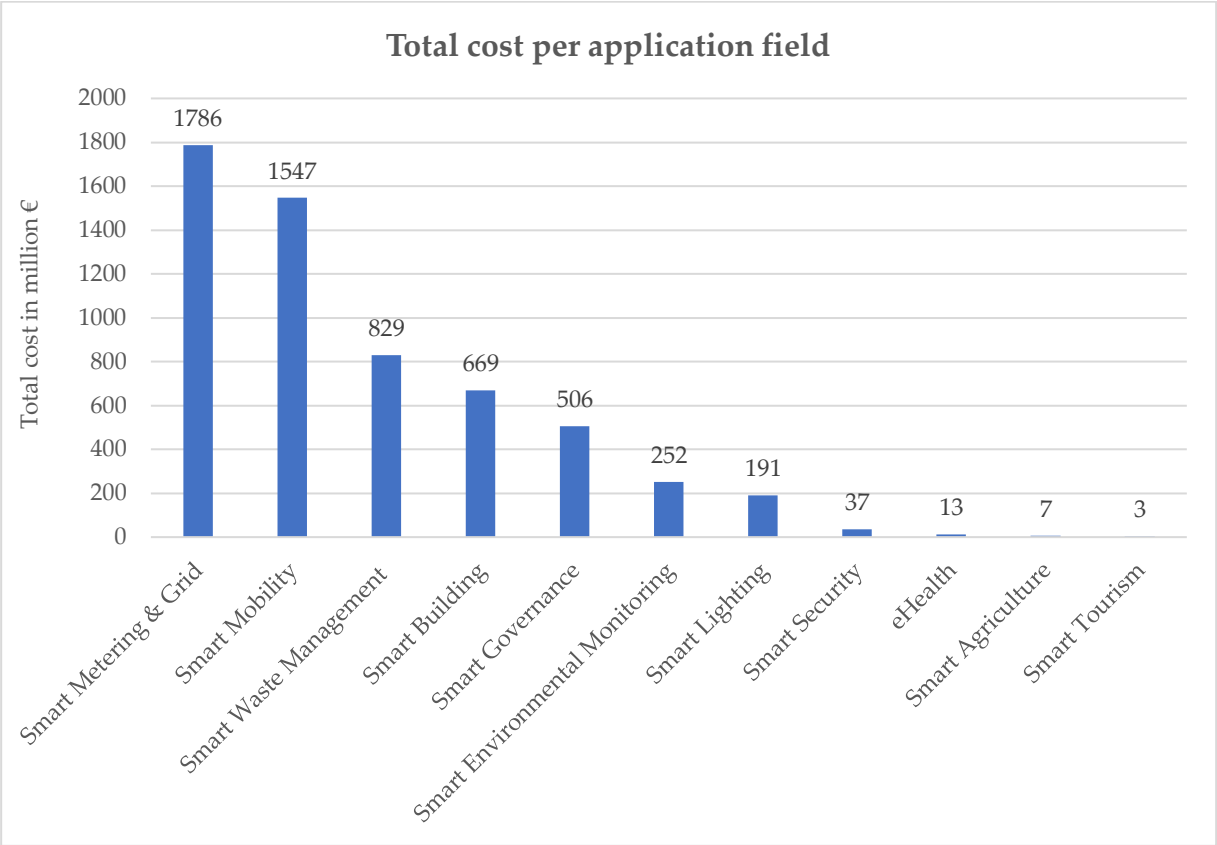


Figure 37: Total cost per application field

The application field that has shown the highest investment value from 2015 to 2024 is Smart Metering & Grid, reaching nearly €1.8 billion. This is coherent with the great number of projects involved in this field and the fact that these projects can be applied not only to the electrical grid but also to the gas and water management sectors, making it a broad field. The second most significant application field is Smart Mobility, with investments amounting to nearly €1.5 billion. The prominence of these two application fields (Smart Metering & Grid and Smart Mobility) is understandable, not only because of the substantial number of projects in progress (ranking in the top three) but also due to the typically large investments required for such projects.

Other application fields show significantly lower total investments. Surprisingly, Smart Waste Management ranks third with a value of €829 million, despite having a relatively low number of projects. This is primarily due to a private investment by A2A in Italy, worth €700 million, aimed at installing smart bins and developing recycling plants for materials like plastic, glass, organic waste, and paper.

Significant investment values are also seen in Smart Building with a value €669 million which is coherent since this kind of projects regard buildings regeneration, automated heating and cooling systems but also structural monitoring. The next application field in terms of investments is Smart Governance, with a value of €506 million. It is noteworthy that Smart Governance incurs significantly lower costs compared to Smart Metering & Grid and Smart Mobility, despite being the second in terms of number of projects. This can be attributed to the fact that, besides projects involving the creation of digital twins, the category includes a wide range of projects focused on developing online platforms for citizens, which generally have lower costs.

Still Smart Environmental Governance and Smart Lighting show good values of investment at €252 and €191 million respectively. Instead, Smart Security, eHealth, Smart Agriculture and Smart Tourism registered much lower values, also influenced by the lower number of projects available.

3.2.5. Average cost per application field

An additional interesting data point to analyze is the average cost of these projects to understand which application fields involve the most expensive implementations. In this analysis, shown in *Figure 38*, it is important to note that the average was calculated excluding outlier values that would have made the values extremely biased. Moreover, as in the previous analysis, both Italian and the rest of Europe data have been included. A clear example of outlier is the €700 million investment by A2A in Smart Waste Management, as described in the previous analysis.

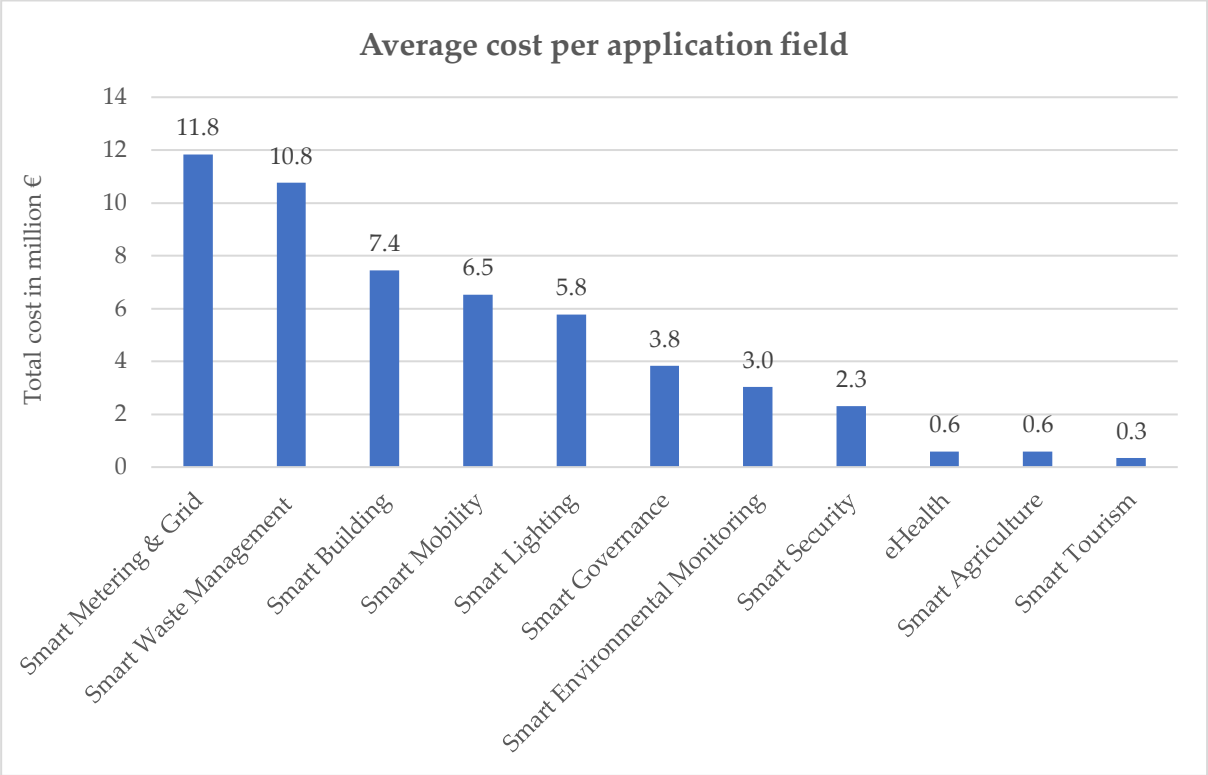


Figure 38: Average cost per application field

This highest average cost for projects has been registered for Smart Metering & Grid (€11.8 million) and this is reasonable since it is clearly associated with the fact that these projects include the installation of smart meters and the modernization of the entire grid, encompassing both hardware components like sensors and network equipment, and software for data management and security. Additionally, the communication infrastructure needed to ensure robust and secure communications through advanced protocols adds to the costs. The installation and maintenance of large-scale projects are also significant expenses that impact on the overall cost but are essential for the proper functioning of these systems. Another particularly expensive component is the integration of photovoltaic panels into smart grids to provide a green energy source that ensures efficient and sustainable operation. These panels, along

with inverters and energy storage systems, add further costs but are crucial for the modernization and optimization of smart grids.

The second application field in terms of average cost is Smart Waste Management, with a cost of nearly €10.8 million per project. This again explains why the total cost described in the previous analysis is so high. Although there are fewer projects compared to other application fields, the average cost is high, even if the outlier valued at €700 million has been removed.

The third application field is Smart Building showing a value of €7.4 million. This average investment value can be justified by high costs associated with upgrading infrastructure, integrating advanced technologies, and meeting stringent energy and safety regulations. These projects aim to enhance energy efficiency and sustainability, leading to significant long-term savings and environmental benefits. The investment also reflects the scale and complexity of transforming traditional buildings into technologically advanced, compliant, and more efficient structures.

Smart Mobility and Smart Lighting have values around €6.5 million and €5.8 million per project, respectively. The value for Smart Mobility might seem low, however, this field also encompasses a wide range of projects, from high-cost initiatives like the purchase of electric public vehicles to lower-cost projects such as the creation of MaaS apps.

The average cost for Smart Governance is around €3.8 million per project, again reflecting a mix of more expensive projects like digital twins and less costly projects like digital platforms for communication with public administrations, as mentioned in the previous analysis.

Smart Environmental monitoring projects have an average value of about €3 million while Smart Security of about €2.3 million. The other application fields have significantly lower costs for projects, probably also because the number of projects found for them was lower. eHealth and Smart Agriculture, at around €600k each, require substantial technological setups for digital health services and precision farming. Lastly, Smart Tourism is the least costly at €344k, involving simpler technologies like digital kiosks and smart ticketing systems.

Table 3 summarizes all the values mentioned in this analysis, showing how the computation has been performed to reach the final average cost of projects per application field. The first column represents the application field, the second one the available data, namely how many investment data were retrieved or each application field. “Total cost” represents the total amount of money for each application field. “Outlier value” specifies which projects have been removed to calculate the average avoiding to get a bias value. In particular, there were only 2 projects categorized as outliers, one for Smart Environmetal Monitoring and one for Smart Waste Management. Subtracting the outlier value from the total cost it was possible to obtain

"Total cost without outlier". Dividing this last value by "available data adjusted", namely the available data without the outlier value, it was possible to obtain the final "Project avg adjusted", which is the value of the average not biased.

Table 2: Computation for project average value per application field

Application field	Available data	Total cost	Outlier value	Total cost without outliers	Available data adjusted	Project avg adjusted
Smart Tourism	9	3,099,963 €		3,099,963 €	9	344,440 €
Smart Agriculture	12	7,145,500 €		7,145,500 €	12	595,458 €
eHealth	22	13,200,000 €		13,200,000 €	22	600,000 €
Smart Security	16	37,069,000 €		37,069,000 €	16	2,316,813 €
Smart Lighting	33	190,804,878 €		190,804,878 €	33	5,781,966 €
Smart Environmental Monitoring	51	251,757,851 €	100,000,000 €	151,757,851 €	50	3,035,157 €
Smart Governance	132	506,311,105 €		506,311,105 €	132	3,835,690 €
Smart Building	90	669,319,042 €		669,319,042 €	90	7,436,878 €
Smart Waste Management	13	829,046,483 €	700,000,000 €	129,046,483 €	12	10,753,874 €
Smart Mobility	237	1,547,394,425 €		1,547,394,425 €	237	6,529,090 €
Smart Metering & Grid	151	1,786,431,175 €		1,786,431,175 €	151	11,830,670 €
Total	766	5,841,579,423 €		5,041,579,423.22 €	764	53,060,036.68 €

3.2.6. Total cost per nation

The objective of this indicator is to understand which nations have the highest active investments within the European context. The sample used for this analysis has been 766, namely the value of investments available excluding *The Ellinikon* project. As said before, the country with the highest investments in smart city projects was Italy, with approximately €4.6 billion invested.

As shown in *figure 39*, the subsequent countries with significant investments have values starting from a maximum of €273 million, showing a huge discrepancy. Again, this is due to the fact that the majority of investment data available are related to Italy in the database. Analyzing the situation in Italy the majority of investment are dedicated to the Smart Metering & Grid and Smart Mobility area, with respectively 30% and 26% of the total. Still a relevant position is occupied by Smart Waste Management with a solid 16%. Some other applications can be seen also in Smart Environmental Monitoring and Smart Governance with 9% of the investments each. Other application fields are less relevant.

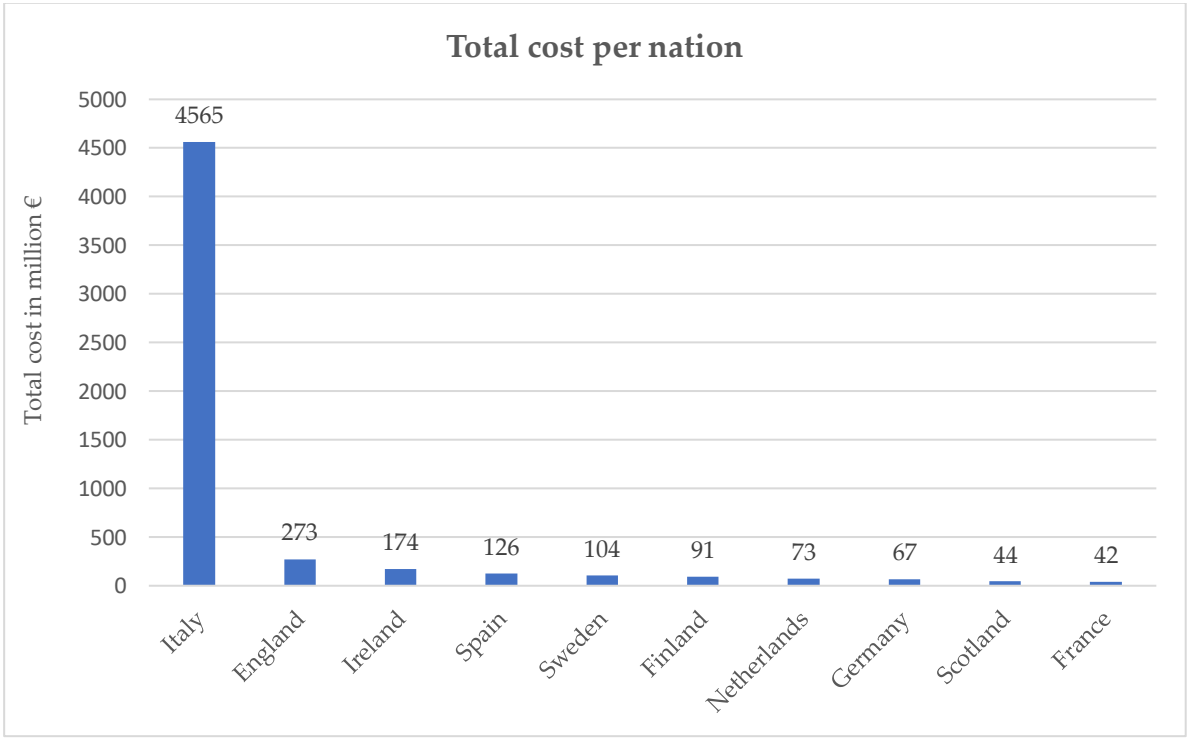


Figure 39: Total cost per nation

In order to have a cleaner view of the investments, *Figure 40* shows the ranking of the top 10 countries excluding Italy in terms of total costs for smart city projects.

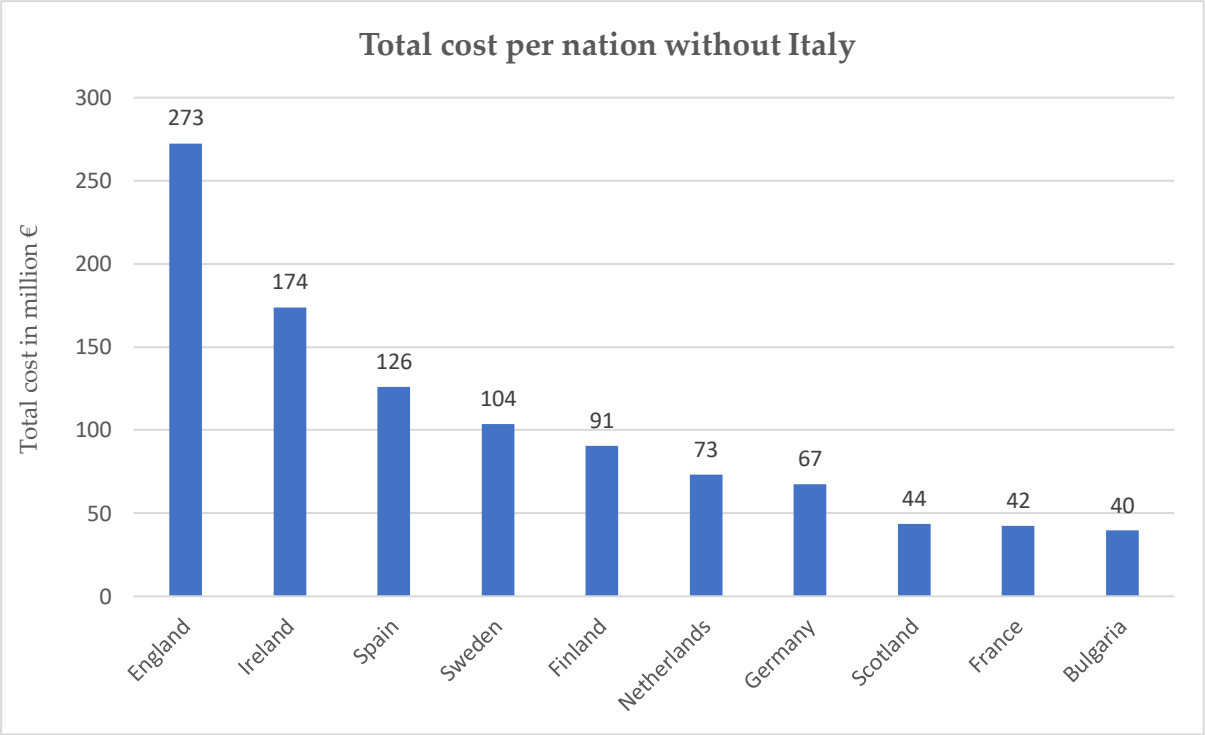


Figure 40: Total cost per nation without Italy

The first noticeable aspect of the chart is that England stands out significantly from other countries with a figure of approximately €273 million, driven by substantial investments primarily in the areas of Smart Metering & Grid and Smart Environmental Monitoring, which account for roughly 34% and 27% of the total investments, respectively. This indicates a clear priority towards the implementation of advanced technologies for energy and environmental resource management.

Ireland ranks second with €174 million, focusing primarily on Smart Mobility initiatives. This suggests a strong commitment to optimizing transportation systems, likely to improve efficiency and reduce emissions.

Spain, Sweden, and Finland have more closely aligned investment values, with €126 million, €104 million, and €91 million, respectively. In Spain, most of the costs were recorded in the Smart Metering & Grid and Smart Building sectors, indicating a balanced approach between modernizing energy infrastructure, and innovating in the building sector. In Sweden, investments were particularly high in Smart Waste Management, reflecting a strong commitment to sustainable waste management. Finland, on the other hand, allocated 52% of its total investments to Smart Metering & Grid, emphasizing the importance placed on energy efficiency.

All the countries included in this classification were also present in the list of the top 20 countries with the highest number of projects. It is interesting to note that England and Ireland, despite having almost half the number of projects compared to Spain, showed much higher investment values. This suggests that projects in these countries are generally more ambitious and capital-intensive.

Once again, a general observation is the predominance of investments from Western and Northern European countries compared to those from Eastern Europe. This trend can be attributed to the greater economic capacity and more developed technological infrastructure present in Western and Northern European countries. Additionally, it is evident that countries with higher investments tend to have more robust and developed economies, as demonstrated by the leading economies of England, Ireland, and Sweden.

One element that might raise suspects is the positioning of France and Germany in seventh and ninth place, respectively. In particular, Germany was among the top three nations in terms of the number of projects, with a total of 104, so this suggests that the possibility of unavailable investment values played a significant role in lowering Germany's ranking.

Regarding France, it had only 29 projects despite being a strong economy. This discrepancy could indicate a research bias, suggesting that not all relevant projects or investments were accounted for in the dataset.

In summary, the chart highlights how the strongest economies in Europe are also leading the adoption of smart technologies, with significant investments in energy infrastructure, Smart Mobility, and sustainable waste management as confirmed in the previous analysis “Total Cost per Application Field”.

3.2.6.1. Total cost per Italian Region

Focusing on Italy, where extensive investment data is available, it is interesting to identify which regions have the highest investments and see if this aligns with the number of projects in each region. The sample used for this analysis has been the 179 projects with investment value available. *Figure 41* represents the situation in Italian regions.

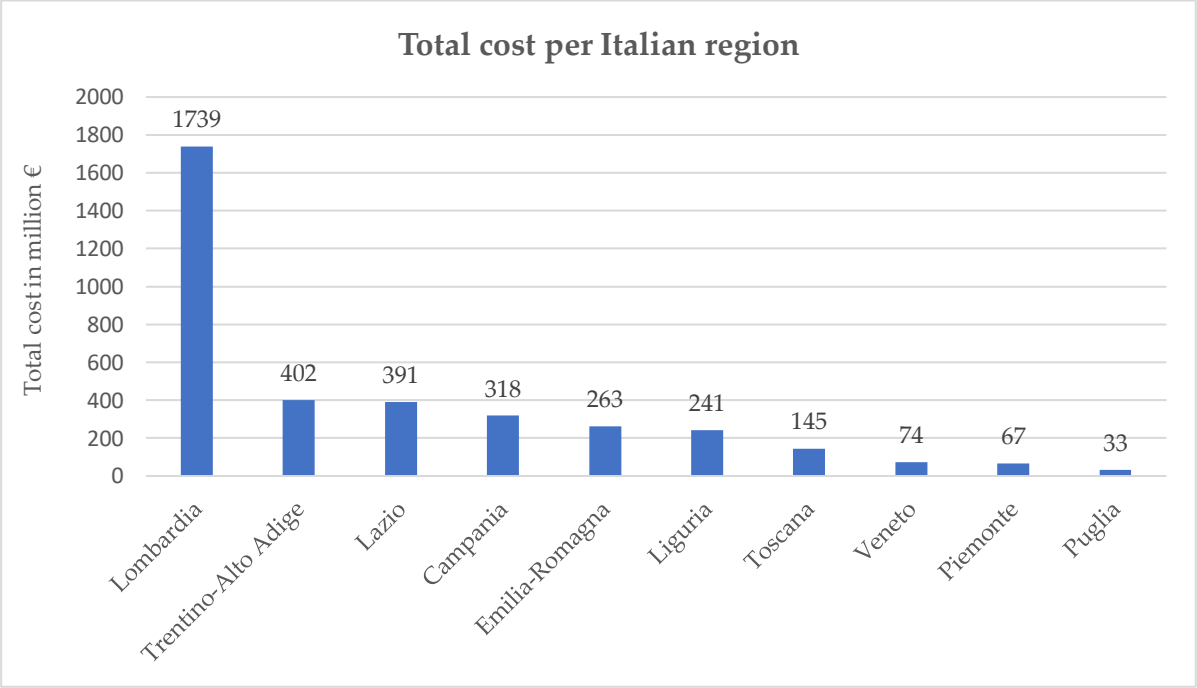


Figure 41: Total cost per Italian region

Clearly Lombardia, with about €1.7 billion is the region with the highest investments, which is consistent with it having the most projects. Investments in smart city projects in Lombardia account for 46% of the total, highlighting its status as the most active region in Italy, largely due to the city of Milan, one of the leading cities in Europe for smart city projects. With a total investment of €1 billion, Lombardia's primary areas of investment are Smart Metering & Grid (50%), Smart Mobility (24%), and Smart Environmental Monitoring (10%). Key projects include the installation of smart gas and electricity meters and the purchase of 350 zero-emission buses in 2024.

Lazio follows with a total investment of €402 million, focusing primarily on Smart Mobility (65%) and Smart Governance (25%). Significant projects in Lazio include the introduction of MaaS solutions, bus crowd management systems, intelligent transport systems, and the implementation of 5G and Wi-Fi. Similarly, Trentino-Alto Adige also shows an investment of €391 million, with major investments in Smart Mobility (65%) for traffic control systems for Cortina 2021 and Smart Building (39%) for building regeneration projects. Campania has invested approximately €318 million in projects,

with a major focus on Smart Mobility (69%), including a significant investment of €250 million for the purchase of electric trains. Emilia-Romagna and Liguria both have investments around €250 million, each accounting for 9% of the total. Emilia-Romagna's investments of €263 million include notable energy projects, such as the creation of a €40 million geothermal plant for heat and electricity production. In Liguria, with investments amounting at €241 million, most projects are concentrated in Smart Mobility and Smart Governance, including the development of a digital twin for the comprehensive management of urban mobility in Genova.

3.2.7. Number of projects funded by the European Union

This indicator and the ones that will follow for the investment analysis at European level, aim to examine in detail the European Union's support for smart city projects and the promotion of innovation. Since the data needed for these analyses are exclusively contained in the database created specifically for this thesis, the sample analyzed includes 472 projects from 2021 to 2024. The number of projects funded by the European union are shown in *Figure 42*.

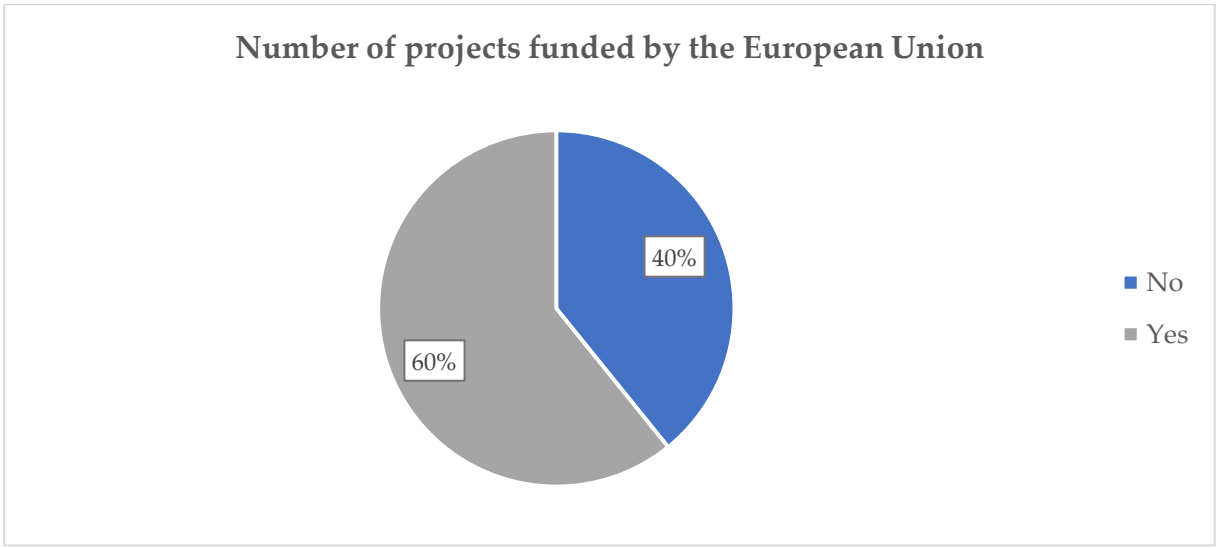


Figure 42: Number of projects funded by the European Union

Figure 42 highlights that 61% of the projects in the database, corresponding to 283 projects, received funding from the European Union. These funds come from various sources and programmes, such as Horizon Europe, Horizon 2020, Next Generation EU and the European Regional Development Fund (ERDF), as discussed in *subsection 1.2.5* of the literature. Additionally, it is important to note that 71 of the projects included in the database were sourced from the "Smart City Marketplace" website of the European

Commission, further reinforcing the crucial role of the EU in promoting smart city projects.

3.2.8. Total cost of projects funded by the European Union

Once the distribution of the number of projects has been defined, it is also interesting to analyze the total cost allocated by the European Union bodies for a total of €2.9 billion. *Figure 43* shows that the proportion completely changed, inverting the two percentage values. Project funded by the European union counted 39% of the total costs with a value of about €1.1 billion. This indicates that the projects funded through European Union programmes and funds have lower allocation of costs compared to the ones funded through other modalities like other public entities (national governments, regional governments, municipal governments, public companies) or private ones. However, having 39% of total costs funded by the European Union represents its great commitment in the smart city context.

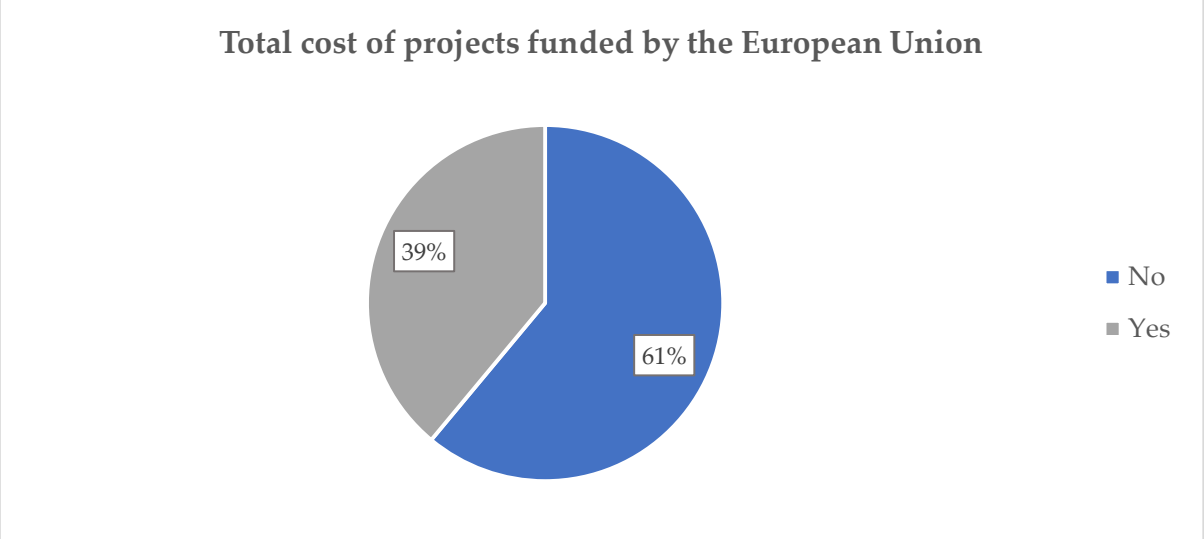


Figure 43: Total cost of projects funded by the European Union

3.2.9. Number of projects per European Union funding source

This analysis aims at understanding how €1.1 billion coming from 283 projects funded by the European Union are allocated among its bodies. *Figure 44* clearly shows that most European projects during the period from 2021 to 2024 were primarily funded through Horizon Europe, with a total of 103 projects supported. Significantly fewer projects were funded through EIT Urban Mobility, Horizon 2020, and Next Generation EU, each with around 50 projects. Additionally, 32 projects were funded through the ERDF.

Horizon Europe and Horizon 2020 are seven-year framework programmes of the European Union. Being this analysis conducted in 2021-2024 timeframe, it makes sense that the number of projects funded by Horizon Europe is much higher compared to Horizon 2020, as Horizon Europe covers the period from 2021 to 2027, while Horizon 2020 spanned from 2014 to 2020. However, there are still projects funded by Horizon 2020 because some projects experienced delays in implementation and thus fell into periods after 2020.

EIT Urban Mobility is a programme primarily focused on supporting sustainable mobility initiatives, aiming to improve the quality of life in cities and develop significant innovations and technologies in the urban mobility sector.

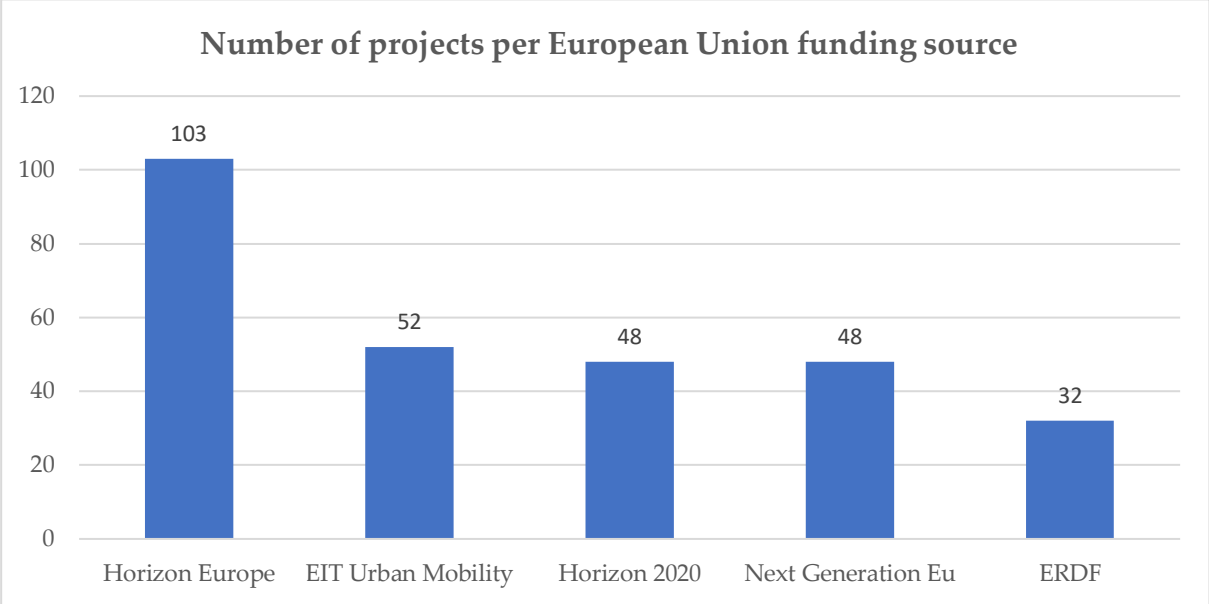


Figure 44: Number of projects per European Union funding source

3.2.10. Total cost of projects per European Union funding source

In the previous indicator, the impact of various tools through which the European Union supports smart city projects was analyzed. However, it is also interesting to understand the actual amounts allocated through each of these tools and verify if the trend is consistent with the number of projects. This information is shown in *Figure 45* and is related to 283 projects funded by the European Union.

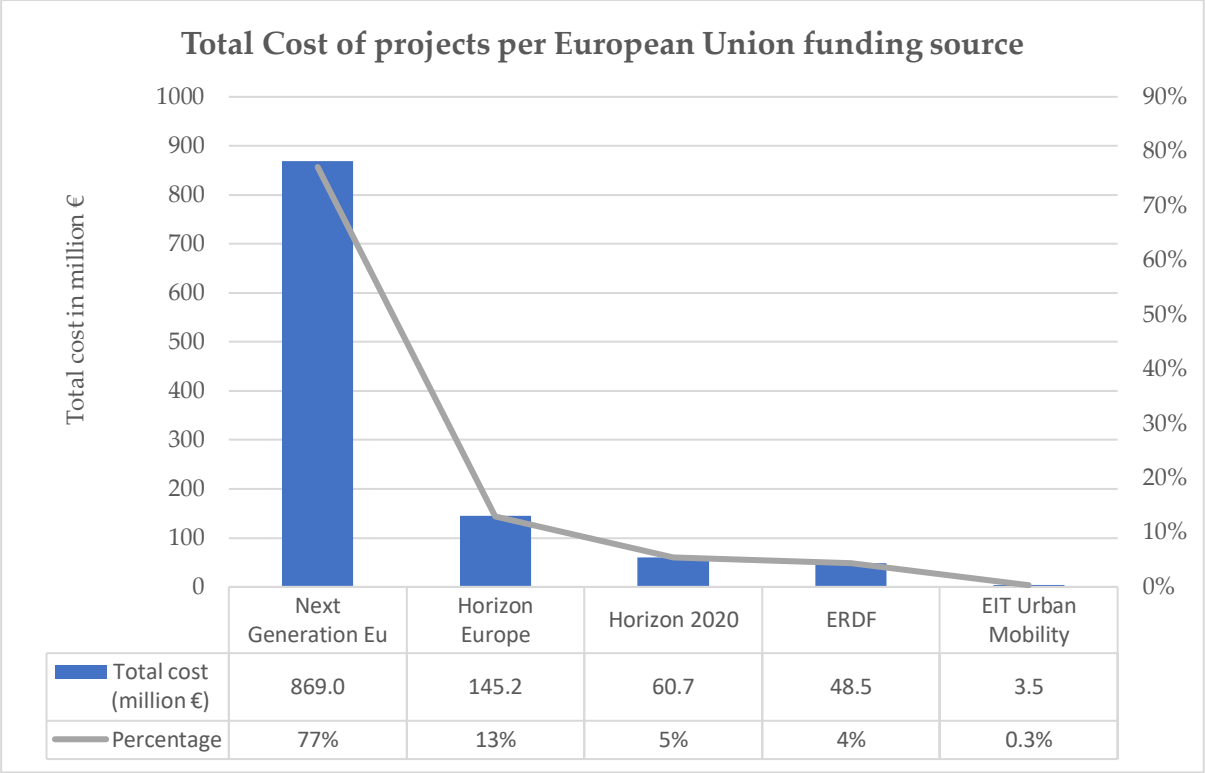


Figure 45: Total cost of projects per European Union funding source

The highest value was recorded for Next Generation EU, with a total of about €869 million invested, entirely from the Italian PNRR. Although the number of projects under this programme was not among the highest, this indicates particularly costly investments per project. Since the analysis shows that 77% of the total European funds belong to the Italian PNRR, it is clear that this data is strongly influenced by the focus of the database on Italy.

Next, the centrality of Horizon Europe emerges, as expected given the time frame considered for the analysis. Following are Horizon 2020 and ERDF, which still show their importance with values between €48 million and €61 million.

It is important to note that Horizon Europe and Horizon 2020 are EU framework programmes aimed at innovation and research, while the ERDF is a structural fund for economic and social cohesion that supports disadvantaged countries and regions.

The framework programmes are centrally managed by the European Union, while the structural funds are managed at a regional level in collaboration with the EU. The higher value of the framework programmes compared to the structural funds is consistent with the smart city context, where innovation and research are foundational elements.

Finally, EIT Urban Mobility, despite having a similar number of projects to Horizon 2020 and ERDF, shows a significantly lower investment value in smart city projects. This is because the programme allocates much less money compared to the framework programmes and mainly aims to help SMEs introduce innovations. A clear example is the financial support to startups for developing MaaS (Mobility as a Service) applications to enable simple and efficient public transport management.

3.2.11. Total cost of projects per application field for each European Union funding source

Once the elements through which the European Union supports smart city projects have been identified, it is essential to delve deeper to understand the specific types of projects that receive the most funding. This detailed analysis will focus on Next Generation EU, Horizon Europe, Horizon 2020, and ERDF. Instead, EIT Urban Mobility exclusively funds projects in the Smart Mobility sector. In *Figure 46* the distribution of the 48 projects among the different application fields of Next Generation EU can be seen.

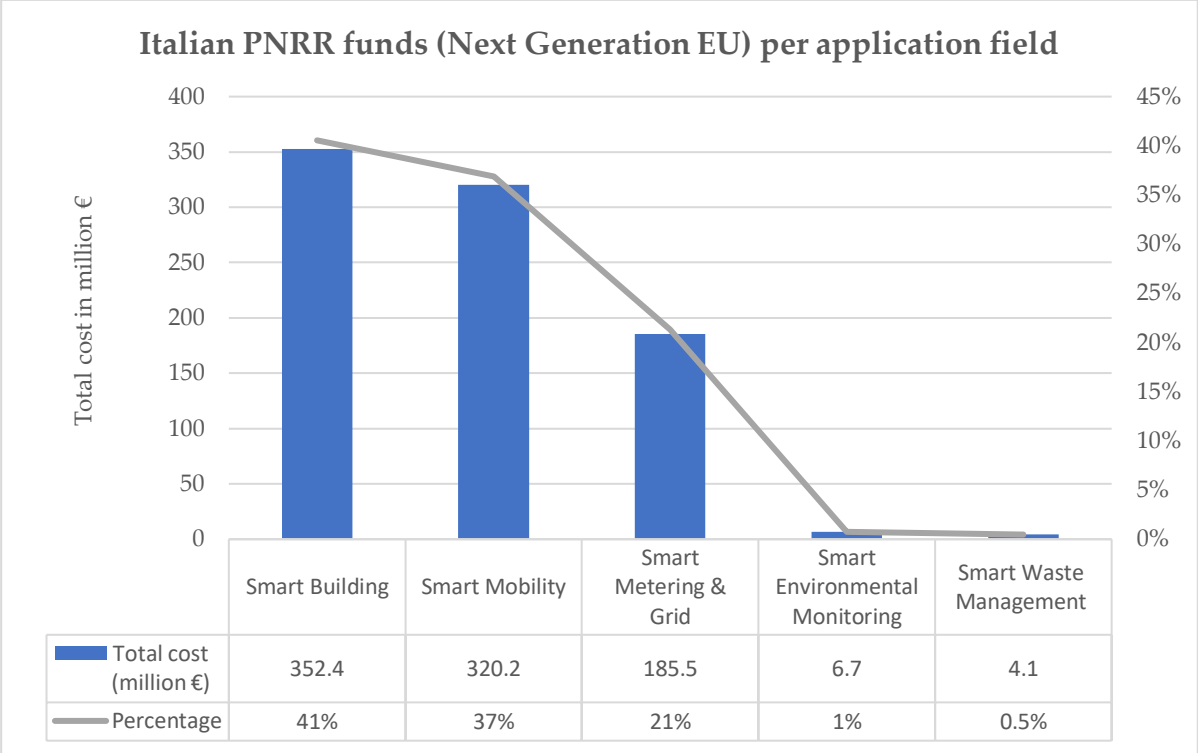


Figure 46: Italian PNRR funds (Next Generation EU) per application field

It is important that in this case this funding programme is entirely related to the Italian PNNR and thus Italian projects. The total amount funded by this programme has been about €869 million.

The graph delineates the distribution of Italian PNRR funds across various smart city application fields, closely aligning with the overarching objectives defined by the PNRR missions, specifically mission 1,2 and 5, which are the ones more aligned with the smart city context.

Smart Building receives the highest allocation with €352.4 million, constituting 41% of the total funds. It seems to be a biased value, but it is mainly due to €275 million for structural monitoring of bridges throughout all the Italian territory. This investment

aligns with Mission 2 of the PNRR, which focuses on enhancing energy efficiency in buildings as part of the broader goal of ecological transition. By promoting energy-efficient buildings, this funding aims to reduce energy consumption and lower carbon emissions, contributing to a more sustainable urban environment.

Smart Mobility is allocated €320.2 million, accounting for 37% of the total. This investment supports Mission 1 and Mission 5. Mission 1 allocates €2 billion to promote digitalization, which includes initiatives such as Mobility as a Service (MaaS). The integration of Smart Mobility systems is a key aspect of this digitalization effort. Additionally, Mission 5 allocates €9 billion for Urban Regeneration, with a significant portion dedicated to improving infrastructure and mobility in cities, aligning with the goals of sustainable and Smart Mobility solutions.

Smart Metering & Grid receives €185.5 million, representing 21% of the total allocation. This investment supports Mission 2's goal of modernizing energy infrastructure. By implementing smart meters and advanced grid technologies, the aim is to optimize energy distribution, enhance efficiency, and support the integration of renewable energy sources. This investment is crucial for creating a resilient and adaptive energy network capable of meeting future demands.

Smart Environmental Monitoring is allocated €6.7 million, or 1% of the total funds. This relatively smaller investment is part of Mission 2's objective to enhance environmental protection and risk prevention through advanced monitoring technologies. These projects will help in early detection and management of environmental hazards, contributing to safer and more resilient urban areas.

Smart Waste Management receives the least funding with €4.1 million, making up less than 1% of the total. This funding is intended to support innovative waste management solutions, aligning with Mission 2's focus on sustainability and circular economy practices. Efficient waste management is essential for reducing the environmental impact of cities and promoting resource recovery and recycling.

Overall, the allocation of PNRR funds as shown in the chart reflects a strong commitment to enhancing the sustainability, efficiency, and resilience of urban environments through targeted investments in key areas. These investments are designed to support the broader goals of Missions 1, 2, and 5 of the PNRR, which collectively aim to promote digitalization, ecological transition, and urban regeneration. By focusing on these areas, the PNRR aims to create smart, innovative, and inclusive cities that are well-equipped to meet future challenges and improve the quality of life for their residents.

Figure 47 illustrates the distribution of the 48 projects funded by Horizon 2020, accounting for about €60.7 million. It is evident that the majority of investments have been directed towards Smart Metering & Grid, accounting for 62% of the total. Significant attention has also been given to Smart Governance and Smart Mobility, including a notable project spanning multiple European countries to test both piloted and autopiloted drones for emergency situations. Smart Building and Smart Environmental Monitoring still received attention with investments between €1 and €2 million.

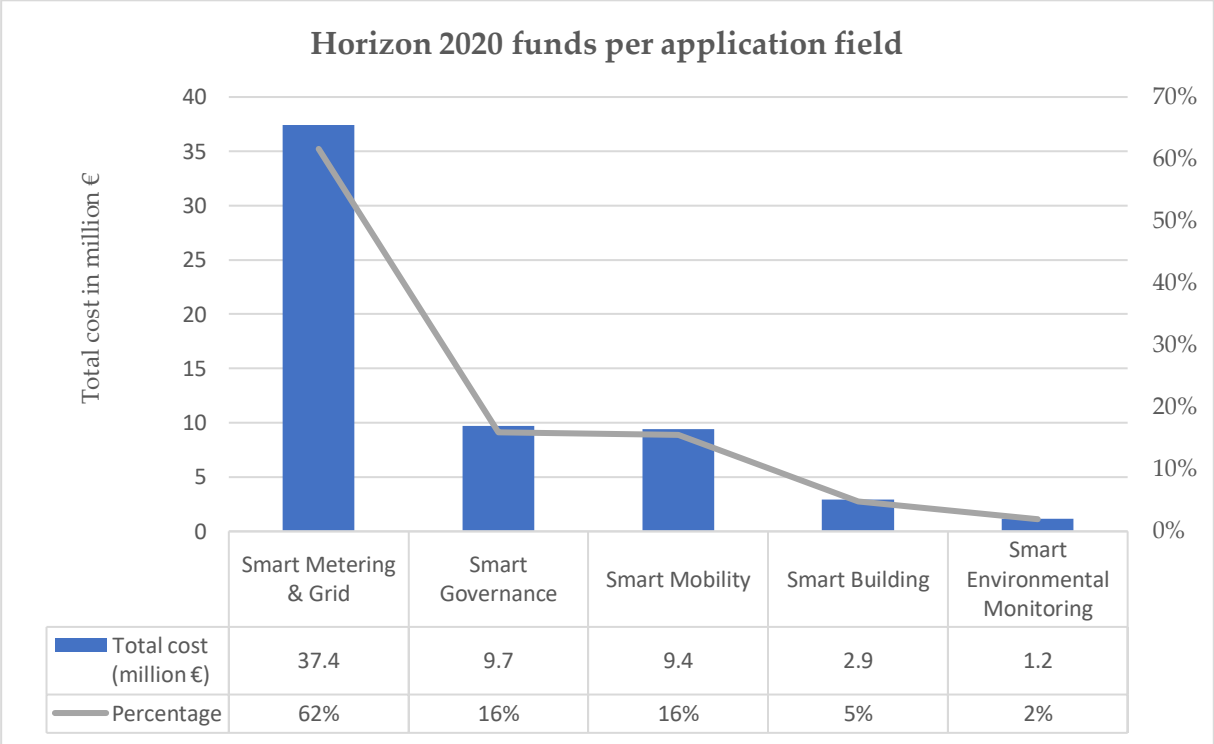


Figure 47: Horizon 2020 funds per application field

In *Figure 48*, the distribution of the 103 projects funded by Horizon Europe, namely about €145 million, the successor of Horizon 2020, is displayed. It is evident that the European Union has continued to prioritize Smart Metering & Grid projects in recent years, reaching an even higher investment level than Horizon 2020, about 68.5 million euros. This demonstrates the EU's ongoing commitment to urban regeneration projects. Over the past four years, starting in 2021, most European projects have focused on the construction of Positive Energy Districts (PED). This aligns with the high value attributed to Smart Metering & Grid, as enhancing the electrical grid's efficiency with the integration of renewable energy is one of the most crucial interventions. Smart Mobility also received significant attention, with more than 40% of the investments, followed by Smart Governance and Smart Building. Additionally, agriculture is gaining considerable importance, as it is among the sectors that have received investments. In summary, Horizon Europe continues to strongly support projects in the areas of Smart Metering & Grid and Smart Mobility, reflecting the European Union's priorities in promoting innovation and urban sustainability.

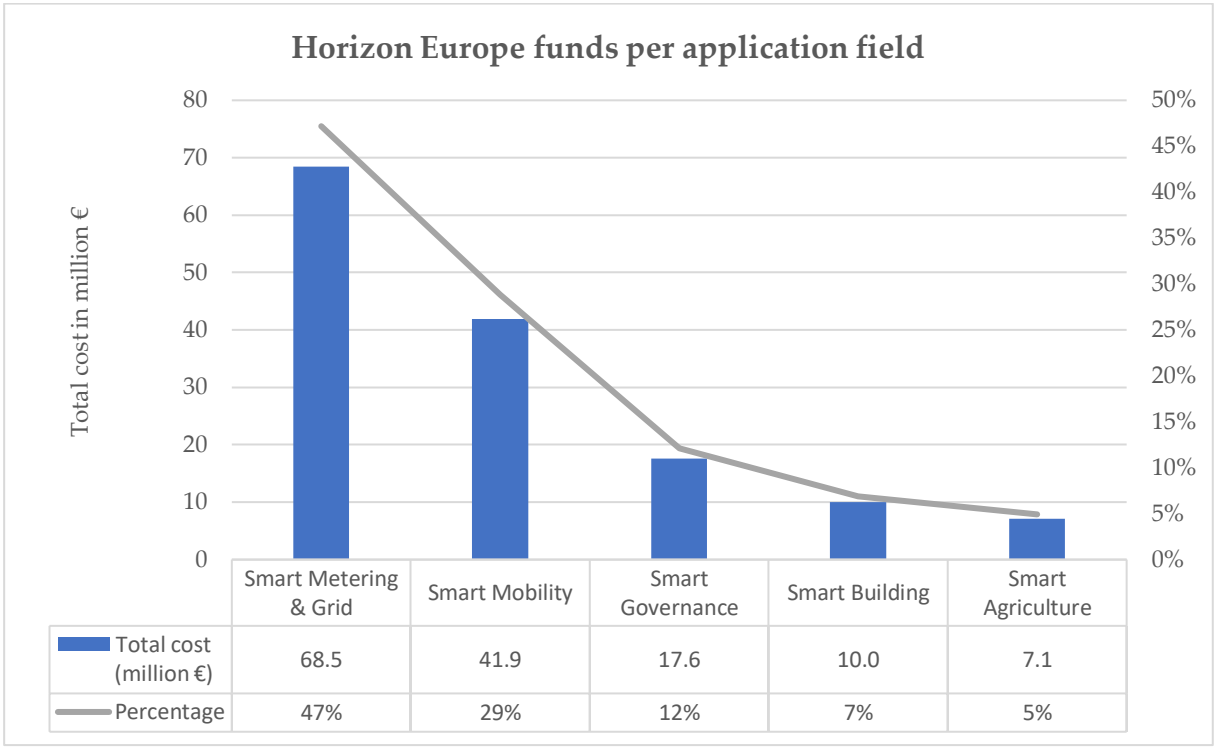


Figure 48: Horizon Europe funds per application field

Therefore, it can be stated that the EU framework programmes have shown a growing interest primarily in energy efficiency, citizen involvement in projects, and sustainable mobility.

The distribution of the costs of the 32 projects funded by the ERDF, amounting at about €48 million, however, differs, as shown in *Figure 49*. The projects with the highest investments are those in Smart Environmental Monitoring, with over €20 million, followed by Smart Governance projects, with more than €15 million invested. Together, projects in these two application fields have accounted for over 80% of the allocated funds. Some attention has been given also to Smart Building and Smart Mobility with funds accounting for €5 and €3.2 billion. Finally, the least funded application field has been Smart Waste Management, with only €100 k.

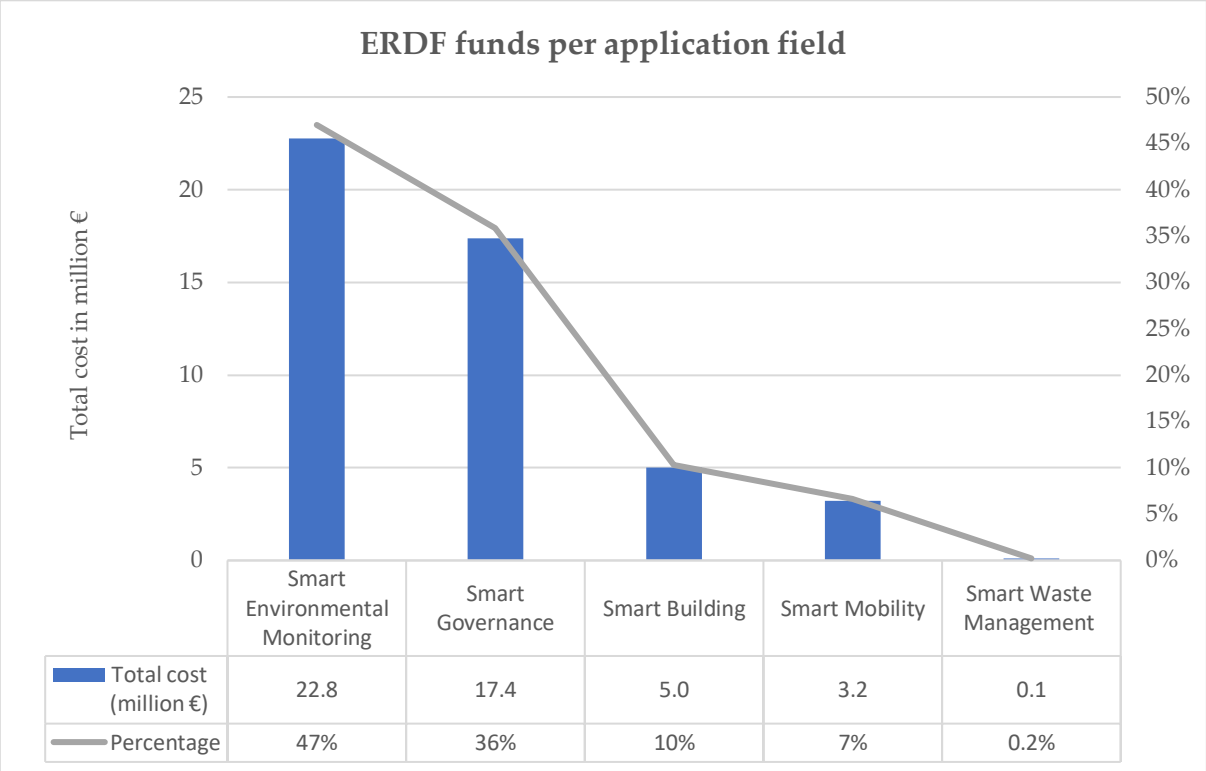


Figure 49: ERDF funds per application field

3.3. Technology analysis

This analysis was conducted exclusively using the database specifically created for this thesis comprising 472 projects that span from 2021 to 2024, offering a comprehensive look at recent technological trends in smart city implementations. The primary aim is to define which technologies have played pivotal roles in shaping the development of smart cities during these years. Furthermore, it's essential to note that this analysis consolidates data without distinguishing between European and Italian contexts.

3.3.1. Percentage of most frequently used technologies

Considering a sample of 472 projects from 2021 to 2024, *Figure 50* provides an insightful overview of the technologies predominantly used in the context of modern smart cities over the past four years. It is important to note that each project may implement multiple technologies. The bar chart indicates the number of projects in which each technology is present.

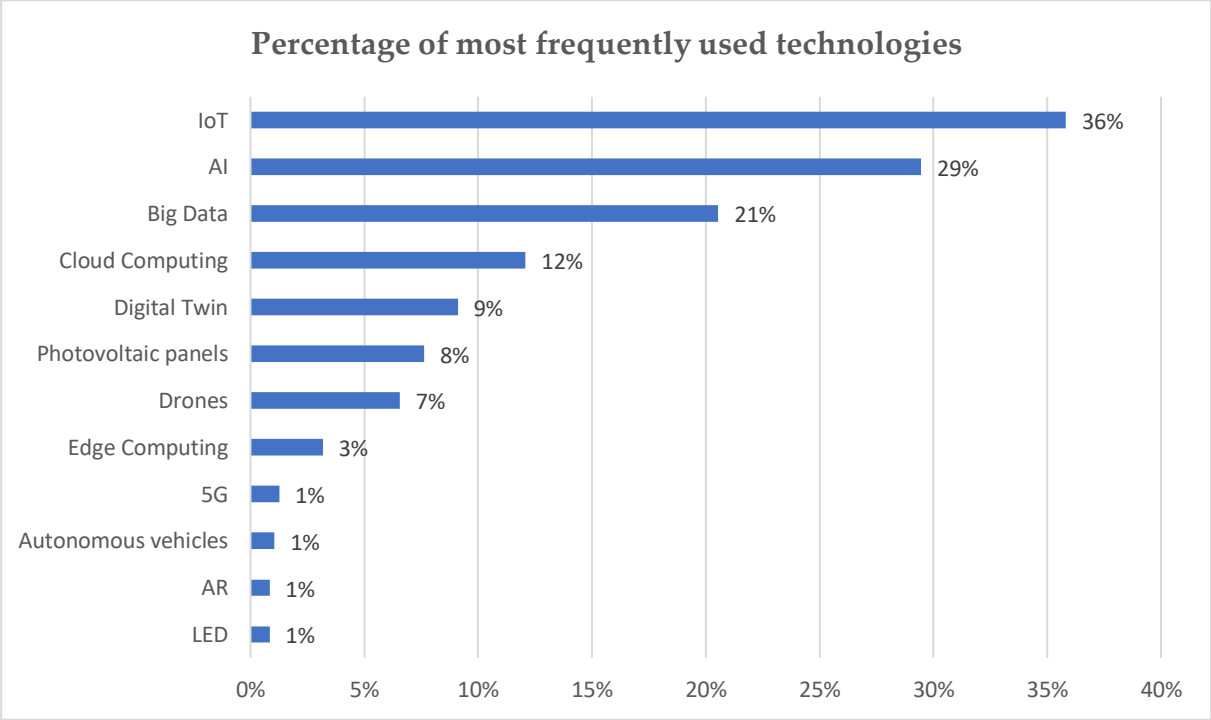


Figure 50: Percentage of most frequently used technologies

As anticipated, the Internet of Things emerges as the leading technology, accounting for 36% of the applications. Recognized in the introductory section of the thesis as the backbone technology, IoT is fundamental for building the infrastructural base of a smart city. Its applications are several, ranging from sensors on traffic lights

monitoring traffic conditions, smart meters, adaptive lighting systems, waste level sensors, to air quality sensors. This category also encompasses RFID technologies, beacons, and communication protocols such as LoRaWAN. The second most used technology is Artificial Intelligence, which accounts for 29% of the usage in projects. AI has become increasingly important and is crucial for performing tasks in a timely and automated manner. Its applications vary widely, including optimization algorithms for routing, lighting regulation, and energy distribution. Big Data also plays a significant role, representing 21% of the usage. This importance is directly related to sensor technology and the vast amount of data that needs to be managed and analyzed. Linked to this concept is Cloud Computing, which makes up 12% of the technology implementations in the projects. Cloud computing provides a central hub for storing and analyzing this vast quantity of data, offering extensive scalability, accessibility, and security. An intriguing aspect is the 9% contribution from digital twins, a technology increasingly used to simulate and optimize urban operations and planning processes. For instance, the TwinEu project planned for 2024 aims to digitize the European electrical grid, creating a shared data foundation among participating countries. Digital twins are extensively used, for example, in recreating road networks to simulate traffic changes or the introduction of new public transport lines. Photovoltaic panels account for 8%, highlighting their indispensable role in sustainable urban regeneration projects aligned with global sustainability goals. A surprising 7% is attributed to drones, utilized in various applications such as territory mapping, monitoring fires and other natural disasters, as well as in urban logistics experiments. Other technologies with smaller percentage points demonstrate their presence and suggest potential for future growth. For example, Edge Computing, accounting for 3%, enhances processing capabilities closer to data sensors to increase speed and reduce cloud workload. 5G is present in 1% of the number of projects, for example the 2024 project “Roma5G” aims at implementing a wide 5G and Wi-Fi network infrastructure in the Italian capital city. At the same level of autonomous vehicles are also noted at 1%, involved in pilot projects to test these solutions. Similarly, LED technology, simple yet effective in reducing energy waste and extending bulb life, and augmented reality, used in tourism for virtual tours of museums and cities, each hold a place in the technological landscape of smart cities.

3.4. Data usage and valorization indicators

The aim of this type of analysis is to understand how data are used and how they can be crucial in the smart city context, becoming a primary source of value. This analysis was also conducted using the sole database created for this thesis, without

distinguishing between Italian and European territories. Thus, it is being discussed a dataset of 472 projects from the recent period spanning 2021 to 2024.

3.4.1. Data usage distribution percentage

As previously defined in the methodology, data collected through sensors and applications are crucial for making more informed decisions and can be utilized in various ways. Considering a total availability of 472 project for this analysis, the most significant use of data, as can be observed in *Figure 51*, is for providing services to citizens, accounting for 54%. This aligns with one of the foundational elements of the smart city concept, which is to enhance the quality of life for residents by introducing new services and optimizing existing ones. The second most common data usage, emerging from this analysis, is the surprising value of 28% for sharing data with public or private stakeholders. This indicates a growing interest in collaboration among various entities to deliver more comprehensive services to citizens through a common data platform accessible to all involved parties. This percentage is supported by many European projects that operate on the principle of testing solutions in pilot cities, then developing best practices to apply in follower cities. This approach aims to have shared data across participating countries to guide projects in future implementations. Finally, the smallest share of data usage, at only 18%, is for internal purposes, such as improving internal processes. The relatively low figure compared to the other uses of data shows how the smart city concept is increasingly evolving toward a citizen-centric model. However, it's important to consider that the other data uses also contribute to process efficiency since focusing on the citizen indirectly leads to streamlined operations.

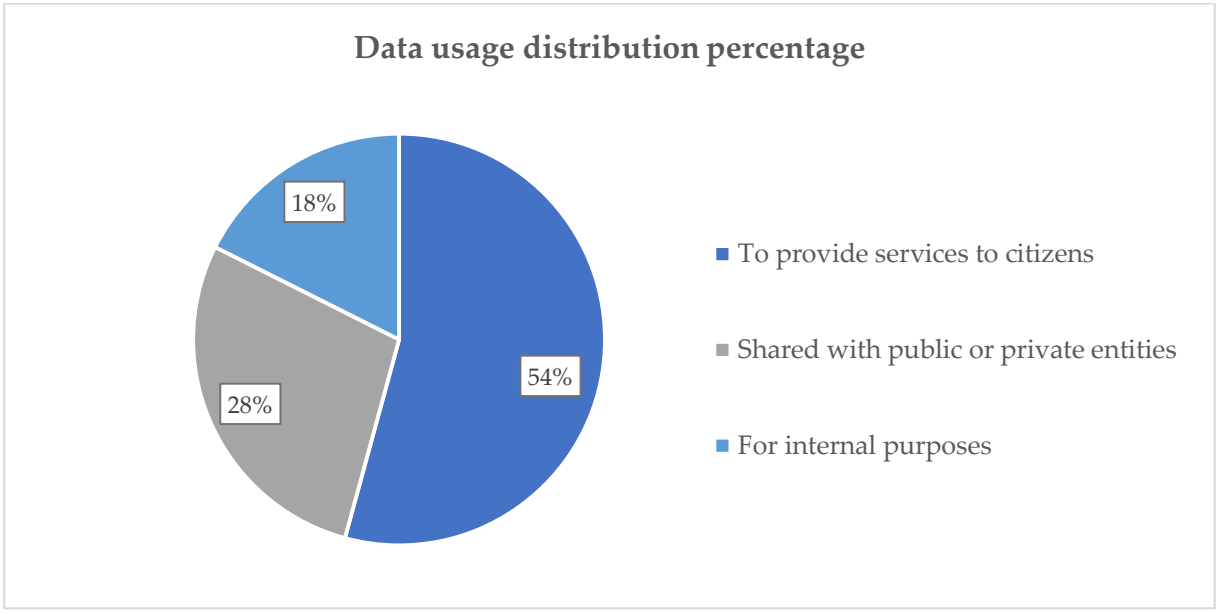


Figure 51: Data usage distribution percentage

3.4.2. Data usage distribution percentage per application field

At this point, it is interesting to understand how data are used across various application fields. Always considering the dataset of 472 projects, application fields such as Smart Metering & Grid play a crucial role in directly enhancing citizen services with values of about 60%. This is achieved through real-time energy monitoring and efficiency improvements, which have a tangible impact on both residential and commercial users. The application of data in these sectors ensures that citizens benefit from reduced energy costs and a more reliable power supply, thereby increasing overall satisfaction and comfort within the urban environment. Similarly, Smart Mobility and Smart Lighting are primarily focused on improving the daily urban experience and managing urban mobility, namely providing services to citizens, with values over 60%. For instance, smart transportation systems utilize data to optimize route planning and reduce congestion, which not only speeds up travel times but also contributes to a reduction in urban air pollution. Smart parking systems leverage real-time data to inform citizens of available parking spaces, significantly reducing the time spent searching for parking and thus lowering frustration and unnecessary fuel consumption. Furthermore, smart lighting systems use data to adjust lighting based on real-time environmental and traffic conditions, which enhances public safety while also conserving energy.

On the other hand, sectors like Smart Agriculture and Smart Waste Management are geared more towards internal operational efficiencies, with values of respectively 100% and 44%. In smart agriculture, data-driven technologies such as crop monitoring systems allow for precise agriculture, enhancing yield while reducing waste and inputs such as water and fertilizers. Smart waste management systems utilize data to optimize collection routes and schedules, which leads to more efficient operations and a reduction in operational costs.

There is a notable trend towards collaborative data sharing between private or public entities, especially in fields like Smart Environmental Monitoring (38%) and Smart Governance (59%). These sectors often share data with both public and private entities to support joint efforts in critical areas such as pollution tracking and response strategies. By sharing data, cities can better coordinate their responses to environmental challenges, plan sustainable urban developments, and engage in proactive governance that anticipates the needs of the citizen.

Finally, areas such as Smart Security, Smart Tourism, and eHealth focus predominantly on providing services for citizens, with values above 80%. Smart security systems utilize data to enhance public safety through better surveillance and quicker response capabilities. In the tourism sector, smart technologies provide tourists with real-time information and guidance, greatly enhancing their experience and satisfaction. eHealth applications use data to improve healthcare delivery by

providing timely medical information, facilitating remote care, and personalizing patient treatment plans.

3.4.3. Data valorization distribution percentage

A crucial element in the context of data valorization is the way data is effectively utilized once it has been acquired. Using 472 projects as available data, as illustrated in *Figure 52*, it is noted that 63% of data valorization occurs in a prescriptive manner. This means that data usage not only facilitates understanding of how to improve operations but also optimizes the decision-making process by enabling the analysis of various potential scenarios.

The next level is adaptive valorization, which accounts for only 17. Unlike prescriptive valorization, in this mode, data becomes highly flexible and is processed in real-time. This allows for immediate decision-making, supported by advanced technologies such as artificial intelligence, which can dynamically respond to continuously changing data.

Finally, again 17% of data utilization is descriptive. This means that data is primarily used to understand past events or situations, without further analysis that might influence or guide future decisions. In this mode, data simply serves to illustrate what has happened, without triggering proactive decision-making processes.

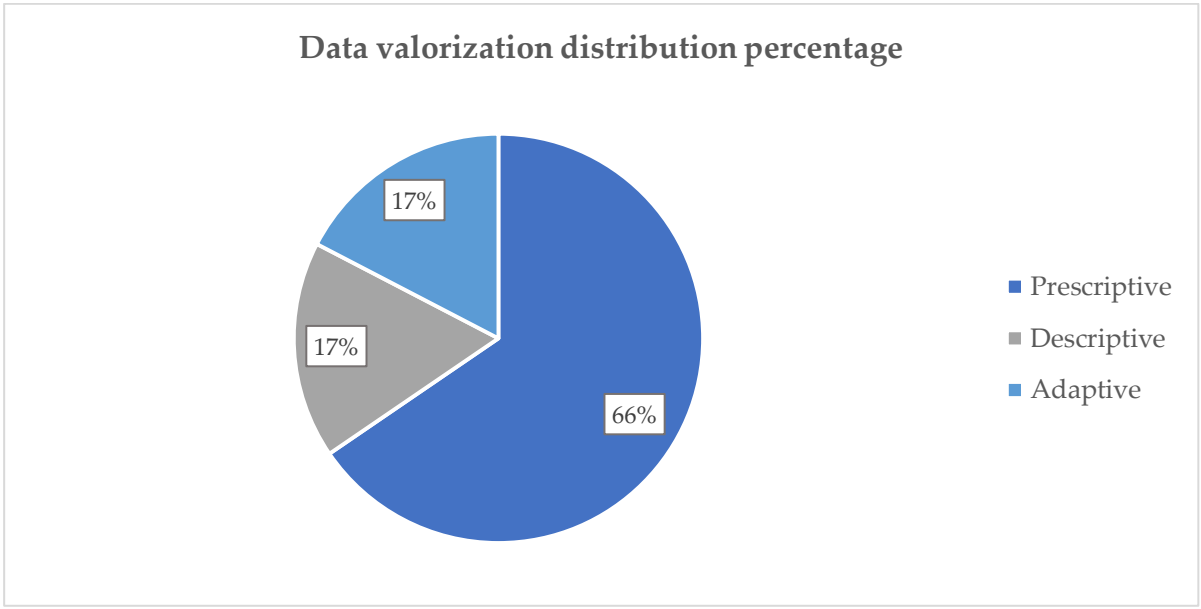


Figure 52: Data valorization distribution percentage

3.4.4. Data valorization distribution percentage per application field

Analyzing data valorization across various application fields, it was discovered that prescriptive data valorization is predominantly observed in the fields of Smart Environmental Monitoring, Smart Governance, and Smart Mobility, all with values exceeding 70%. This indicates a significant reliance on data-driven insights to optimize decision-making processes and enhance efficiency in these critical areas.

Interestingly, the use of adaptive data valorization recorded its highest values in Smart Metering & Grid (58%), Smart Lighting (63%), and smart parking solutions related to Smart Mobility (100%). In these fields, artificial intelligence plays a crucial role by dynamically adjusting key operational parameters such as electricity flow in smart grids and the intensity of public lighting in real-time, thereby ensuring optimal energy usage and enhanced public convenience.

On the other hand, descriptive data usage was notably prevalent in fields like Smart Tourism, where it accounted for 100% of the total. In this context, data is primarily employed to understand and describe current conditions or historical patterns, without necessarily influencing future strategies or operational adjustments. This approach is particularly useful in tourism where understanding visitor behaviors, preferences, and movements can provide valuable insights for service enhancement but doesn't always directly influence immediate operational decisions.

3.5. Benefits analysis

This analysis aims to identify the most significantly impacted benefits in smart city projects across Europe, delving deeper into each application field to uncover the most recurring benefits. Once again, as outlined in the methodology section, the dataset utilized comprises 472 projects spanning from 2021 to 2024. It is important to note that this analysis does not differentiate between Italian and broader European areas, providing a comprehensive overview of trends across the continent.

3.5.1. Benefits impact frequency

A class of nine benefits, as defined in the methodology chapter, has been identified and in *Figure 53*, the impact frequency on each of them can be observed. The dataset on which the analysis has been performed is of 472 projects with total availability of this kind of data.

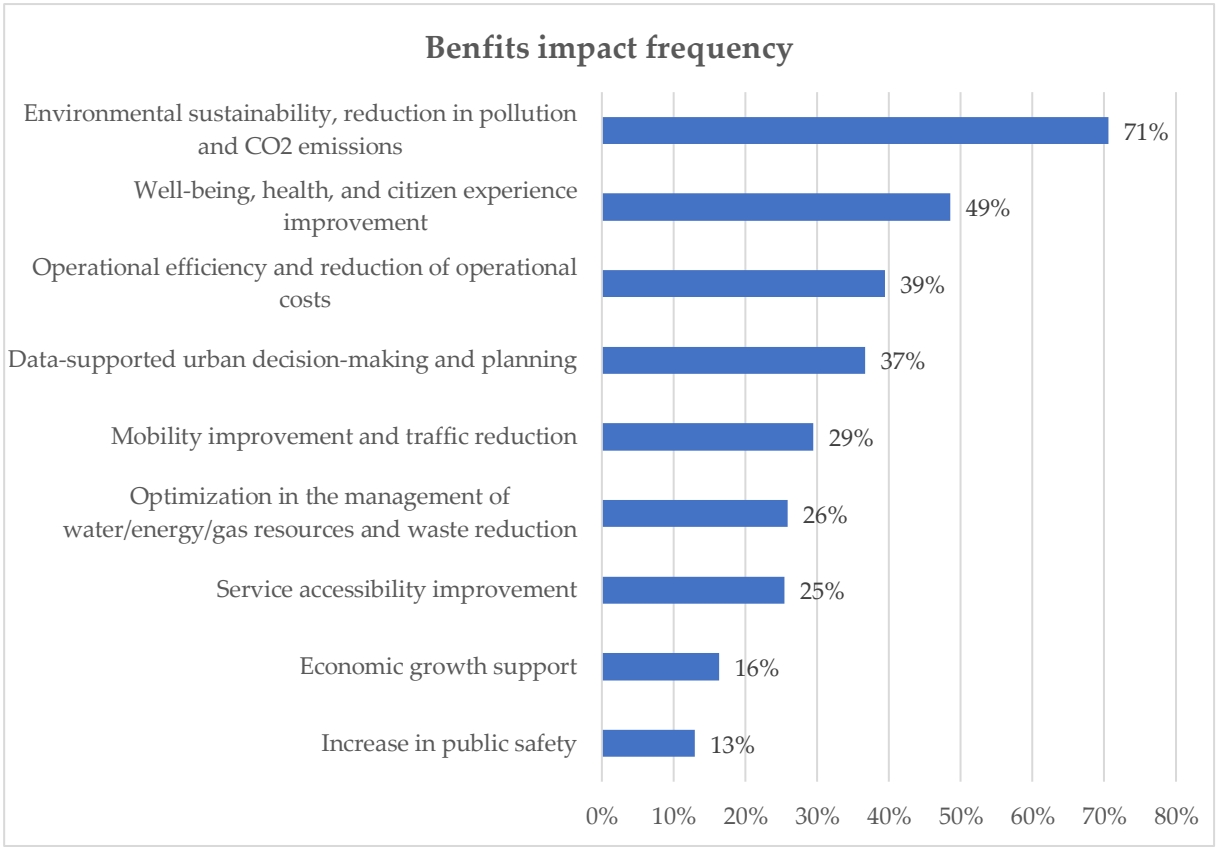


Figure 53: Benefits impact frequency

The most significantly impacted benefit, evident in 72% of the projects, pertains to "*environmental sustainability, reduction in pollution, and CO2 emissions*". This dominant focus reflects a widespread commitment to sustainability and the goal of reducing

carbon footprints as a countermeasure against climate change. The high frequency of this benefit underscores that almost all smart city projects incorporate sustainability goals, significantly influenced by global frameworks shaping these initiatives. This trend highlights the shift towards the concept of "*Smart Sustainable Cities*", as emphasized in the literature. A clear example can be found in Smart Mobility projects where the use of sharing and public transportation integrated with electric vehicles undoubtedly reduces pollution, both by decreasing the number of polluting vehicles on the road and because the environmental impact of electric vehicles is minimal. Similarly, in the field of Smart Metering & Grid, monitoring consumption and subsequent energy distribution based on actual consumption, integrating renewable sources such as photovoltaic panels, can lead to significant environmental sustainability benefits by avoiding energy wastage and producing clean energy.

Another major benefit, present in 50% of the projects, is "*well-being, health, and citizen experience improvement*". This prevalence demonstrates a core objective of smart city projects to enhance the quality of life within urban settings. This goal spans various project types in Smart Mobility, Smart Governance, Smart Building, eHealth, and Smart Environmental Monitoring, illustrating a comprehensive approach to urban development. For instance, in Smart Mobility, having the ability to access all transport and sharing services integrated through a single app, which also facilitates payments, significantly enhances the citizen's experience. Projects in Smart Building where lighting and heating & cooling systems are automatically controlled by the system through sensors and artificial intelligence allow residents to avoid worrying about such utilities and enhance their living experience. Projects in the eHealth realm, such as telemedicine, improve the patient experience by facilitating remote management, and Smart Environmental Monitoring projects continuously monitor air quality, allowing for timely corrective actions if air quality levels become hazardous or in response to catastrophic events like fires, landslides, or floods. Clearly, projects in Smart Governance involving the digitalization of public administration and the ability to provide feedback also present benefits of this type.

Furthermore, "*operational efficiency and cost reduction*," impacted in 39% of projects, showcases widespread initiatives aimed at optimizing city operations such as waste collection, energy distribution, and adaptive public lighting management. For example, with projects in Smart lighting for adaptive lighting, it is possible to know when there are faults and act preventatively, similarly in smart grids. Another striking example is found with the introduction of smart bins in Smart Waste Management, allowing for intelligent waste collection accompanied by routing algorithms that indicate the fastest routes to specialized companies, making trips only when a bin is truly full.

About 37% of projects emphasize "*data-driven urban planning*" as benefit. This significant percentage reflects the crucial role data plays in resource allocation and

decision-making, increasingly utilized in prescriptive and adaptive modes to enhance service delivery to citizens. Projects involving digital twins and smart metering & grid systems exemplify this trend, leveraging data for sophisticated, real-time urban management.

Other noted benefits include "*Mobility and traffic improvement*" (29%) and "*Optimization in the management of water/energy/gas resources and waste reduction*" (26%), often linked to specific sectors like smart Mobility for the former and Smart metering & Grid for the latter.

"*Service accessibility improvement*" (25%) features in diverse projects such as open data platforms in Smart Governance and Mobility-as-a-Service (MaaS) apps that integrate various transport and sharing services.

"*Economic growth support*" and "*increase in public safety*," with 16% and 13% respectively, show less frequent impact. This does not diminish their importance but indicates a stronger focus on sustainability. Economic growth is visible in initiatives like EIT Urban Mobility's Raptor project, supporting startups in creating innovative solutions. The relatively lower emphasis on public safety can be attributed to the fewer number of projects in the Smart Security and disaster management sectors compared to others.

In essence, the ultimate goals of these smart city initiatives are to create sustainable and livable environments that significantly improve the quality of life for residents integrating the use of digital technologies. These two first benefits are spread between all application fields while the cited subsequent benefits are more specific to some application fields. However, a project belonging to a certain application field does not have only but usually has multiple ones, combining specific and more general benefits. A clear example is adaptive smart lighting, which not only improves operational efficiency but also contributes to CO2 reduction through decreased energy consumption.

3.6. SDGs analysis

Throughout the thesis, the importance of the connection between the concept of smart cities and sustainability has been repeatedly emphasized. Recently, there has been increasing discussion about what are referred to as "Smart Sustainable Cities". This topic is thoroughly examined in *subsection 1.2.4*, where the literature on the United Nations' Sustainable Development Goals related to the Smart City paradigm is explored. Therefore, the aim of this analysis is to identify which SDGs are most impacted and to understand how different application fields contribute to these goals, comparing also the results to literature findings. Also this analysis has been conducted

on a sample of 472 projects, namely the database created specifically for the thesis covering the time span between 2021 and 2024.

3.6.1. SDGs achievement frequency

Considering a complete availability of data on the 472 projects in the database, *Figure 54* shows a ranking of the most impacted SDGs.

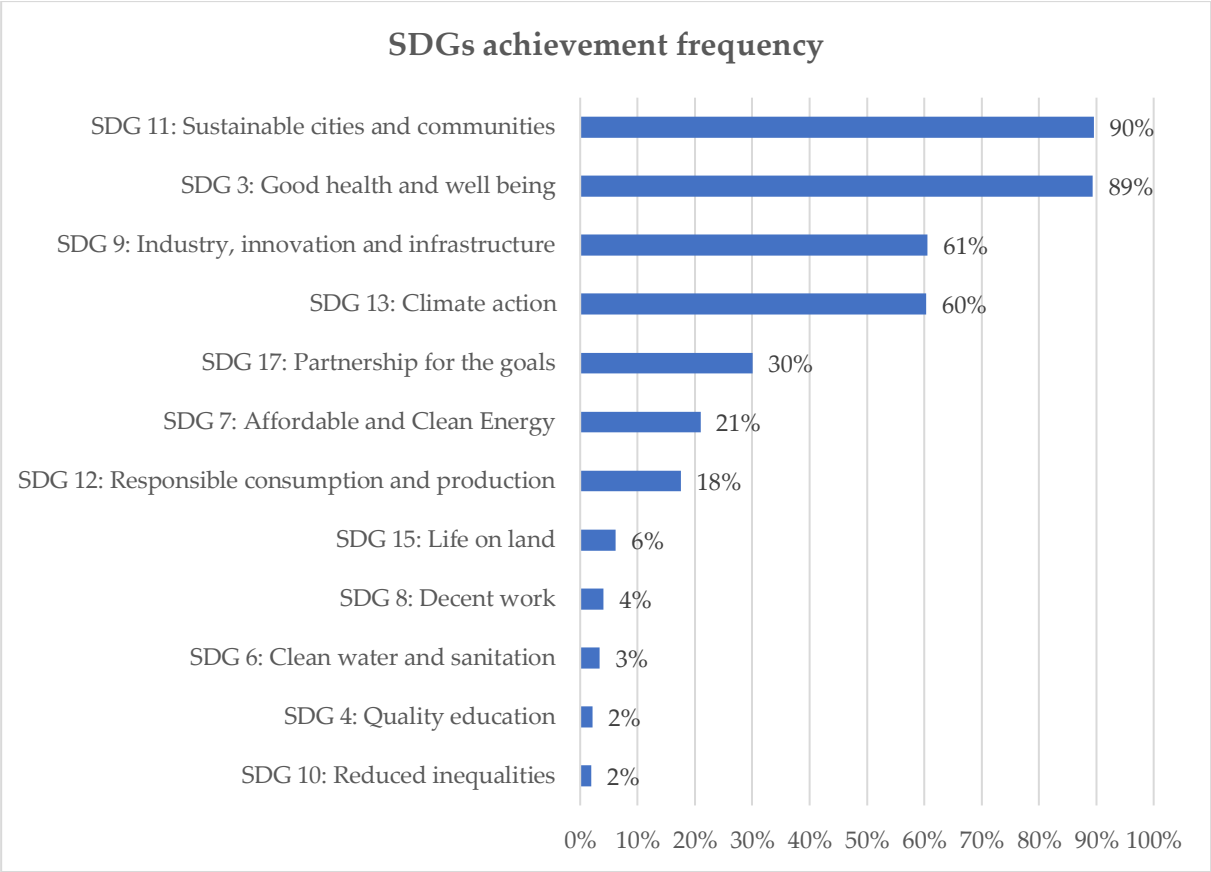


Figure 54: SDGs achievement frequency

SDG 11 (Sustainable Cities and communities) and SDG 3 (Good health and well-being) are the most frequently achieved goals, each being reached in approximately 90% of the projects. This aligns well with the primary objectives of smart city initiatives, which aim to create sustainable cities that use resources wisely, reduce pollution levels, and enhance the quality of life for citizens in terms of health and overall well-being. The high frequency of these goals being met indicates that projects across all application fields contribute to these outcomes to varying degrees. Specifically, SDG 11 focuses on making cities and human settlements inclusive, safe, resilient, and sustainable, making it a goal perfectly tailored to urban environments.

High percentages were also recorded for SDG 9 (Industry, innovation and infrastructure) and SDG 13 (Climate Action), which are commonly achievable through various projects in different application fields. SDG 9 centers on innovation and the use of advanced technologies to improve services, industries, and urban infrastructures highlighting the critical role of technology in smart cities as well documented in many definitions of the concept. On the other hand, SDG 13 focuses on combating climate change. This can be addressed through multiple means, such as smart grids, the integration of renewable energy, the use of electric vehicles in public transport, more efficient waste collection, and continuous air quality monitoring for corrective actions.

Lower percentages were noted for other goals, though notable values were recorded for SDG 17 (Partnership for the goals), which stood at 30%. This clearly shows the fundamental importance of partnerships in project implementation, involving both private and public actors. Such collaborations leverage the combined knowledge, expertise, and resources to achieve desired outcomes more quickly and effectively. Often, projects involve the European Union, governments, and specialized companies for solution implementation.

SDG 7 (Affordable and clean energy) and SDG 12 (Responsible production and consumption) also show good percentages at 21% and 18%, respectively, but these goals are typically achieved through projects in specific application fields. The value associated with SDG 7 is largely tied to smart metering and grid projects, particularly renewable energy communities, highlighting significant interest in building distributed networks that integrate renewable energy sources like solar panels. SDG 12, on the other hand, is linked to smart waste management projects and, again, to the smart metering and grid field.

Other application fields depicted in the chart show significantly lower percentages. For example, SDG 15 (Life on Land), which registers a 6% impact, is mainly attributable to Smart Agriculture projects and Smart Governance initiatives aimed at creating green areas to preserve natural ecosystems. SDG 8 (Decent Work and Economic Growth) is a focus in 4% of the projects, suggesting that some smart city initiatives aim to foster economic opportunities and ensure decent work conditions. This percentage seems to be quite low given the fact that innovative projects give the opportunity to innovate industries and create new jobs, however this is linked to the fact that searching for projects, this SDG was not always explicitly mentioned. SDG 6 (Clean Water and Sanitation) appears in 3% of the projects, highlighting efforts to improve water management in smart metering and grid-related projects. Lastly, SDG 4, (Quality Education) and SDG 10 (Reduced Inequalities) are each targeted by 2% of the projects, showing that some initiatives aim to enhance educational opportunities and reduce social inequalities in the urban population services.

Overall, the analysis of data from this thesis' database aligns with the literature, highlighting SDG 11, SDG 3, SDG 9, and SDG 13 as the main goals. This confirms that the primary focus of smart city projects is on creating sustainable, healthy, and innovative urban environments.

3.7. Citizen engagement analysis

The role of the citizen within smart cities is becoming increasingly significant. As highlighted in the literature, in the latest generation of Smart Cities (3.0), collaboration and citizen engagement, both for feedback and to drive innovation, are crucial focal points. Particularly, Smart Governance has gained substantial importance, being the second most prevalent application field in terms of the number of projects. This underscores the essential nature of tools such as workshops, open data platforms, conferences, and apps for more targeted urban planning.

It's also important to note that the analyses presented in this section have been conducted using the newly created database specifically for this thesis, with a totality of 472 projects. Dedicated columns were established to explore and address the role of the citizen comprehensively.

3.7.1. Percentage of project with citizen engagement

Considering complete availability of data (472 projects), in *Figure 55*, it is evident that there is an almost equal balance of citizen involvement in smart city projects. This clearly indicates a trend towards inclusivity and public participation in the process, even if there are wide improvement margins.

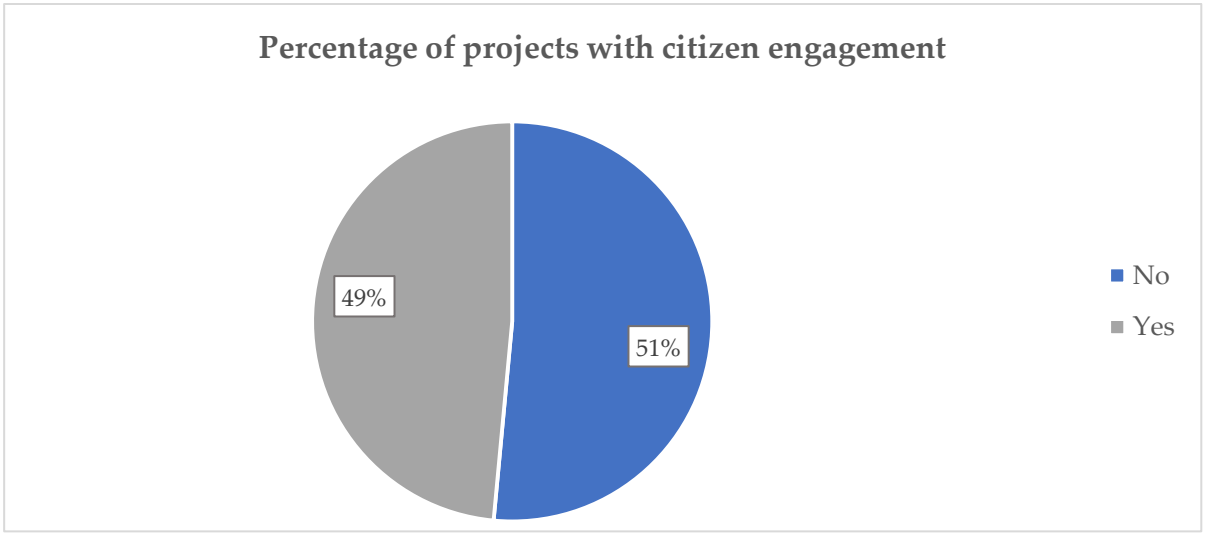


Figure 55: Percentage of projects with citizen enegagement

However, the data just presented does not provide specific insights into the trend of citizen involvement over the past few years. For this reason, a temporal analysis was conducted, as shown in *Figure 56*. This analysis reveals a clear upward trend in citizen involvement in smart city projects from 2021 (28 projects) to 2023 (93 projects), followed by a decline in 2024. Nevertheless, this decline in 2024 does not indicate a decrease in interest in co-participation. Instead, it can be seen as a positive outcome since the analysis only extends to April 2024. This suggests that if the same trend continues, 2024 could end with an even higher number of projects than 2023, showing over the past 4 years an increasing trend of interest in collaborating with citizens.

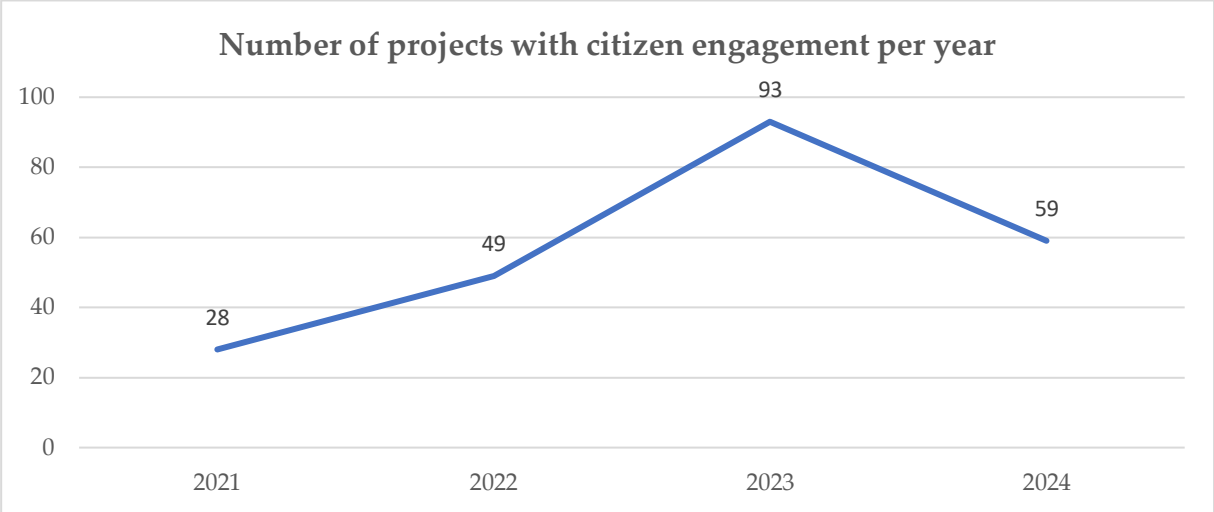


Figure 56: Number of projects with citizen engagement per year

3.7.2. Most used citizen engagement tools

Once it is understood that citizen involvement in project initiatives is becoming increasingly important, it is interesting to delve into how they are actually engaged. There are several recurring methods used to ensure active and meaningful citizen participation.

Among the most common methods are workshops, which offer citizens the opportunity to actively participate in collaborative working sessions where they can share their ideas and contribute to the development of solutions. For example, a workshop on "New Mobility Concepts" was conducted to identify user needs and find ways to improve public transport systems and digital solutions in Vitoria-Gasteiz in Spain. During the workshop, participants collaborated on various co-creation activities aimed at reflecting on new digital mobility technologies and developing ideas based on mobility needs.

Another widely used engagement method is feedback via mobile applications. This allows citizens to provide real-time input on various initiatives and services through dedicated apps. For instance, a project in Cardiff included a community feedback mechanism through a mobile application, allowing residents to report the status of waste bins and propose improvements, fostering a sense of civic engagement and responsibility.

Participation in surveys is another frequent mode of engagement, allowing the collection of valuable data on citizens' opinions and needs. This approach was used to conduct a survey among citizens in Banja Luka (Bosnia and Herzegovina) to express their comments on the solar bus stops enabling device charging, Wi-Fi and delivering advertising digital spaces.

Participation in testing solutions is another important method. Citizens are often invited to test new solutions and provide feedback on them. For example, citizens were involved in testing the developed app and providing feedback on it, contributing to the continuous improvement of the solution.

Focus groups and discussion groups are often used to gather qualitative and in-depth input. Incentives for sustainable behaviors, such as collecting points and rewards for eco-friendly actions, are used to promote participation and environmental responsibility.

Gamification transforms participation into a game, making the interaction more engaging. Access to virtual simulations allows citizens to better visualize and understand proposed changes, such as the digital twin modeling the future development of pedestrian areas in the municipality of Fällanden (Switzerland).

Another method is the use of shared platforms with public administrations to make information transparent and accessible to all, facilitating an open and constant dialogue with users to adapt services to their needs. An example is the use of innovative digital platforms for engagement, such as the one adopted by the Metropolis of Dijon to inform and involve citizens in its sustainable development initiatives.

Finally, renewable energy communities are another significant method of citizen engagement. These communities involve citizens directly in the production and management of renewable energy, promoting sustainable practices and energy independence. For instance, citizens and local businesses are encouraged to participate in community energy projects where they can share the benefits of locally produced renewable energy.

4 Conclusions

This chapter aims to present the conclusive and aggregated results of the analysis conducted, providing a comprehensive snapshot of the current state of the art of the Smart City projects across Europe, with a deeper focus on the Italian context when necessary. It begins by highlighting the main findings derived from the analysis in *Chapter 3*, then discussing the limitations of this thesis, and concluding by suggesting possible future research directions. It is crucial to note that the analyses aimed to cover the key aspects of smart city project implementation, including geographical and temporal distribution, as well as identifying the most significant application areas. Furthermore, extensive analyses were conducted regarding investments, technologies utilized, achievable benefits, the most involved SDGs, data utilization, and the role and involvement of citizens. By addressing these dimensions, the chapter provides a comprehensive view of the progress and challenges associated with smart city initiatives.

4.1. Main findings

The analysis of smart city projects in Europe, with a particular focus on Italy, covering the period from 2015 to 2024, has revealed several crucial aspects and led to important conclusions about the current and future state of smart cities.

In the European context, there has been a general increase in the number of smart city projects, although external events have influenced their progress. Notable events include the 2015 Paris Agreement, the establishment of the United Nations' Sustainable Development Goals, and the Covid-19 pandemic in 2019. The pandemic significantly impacted the number of initiatives between 2019 and 2020, as countries focused on combating the disease. However, starting from 2021, the number of projects grew significantly due to the introduction of programmes like Horizon Europe and Next Generation EU by the European Union. National recovery and resilience plans played a crucial role in promoting innovation and reducing climate impact. The expected growth in 2024 suggests that these interventions are successfully fostering sustainable and technological development in European cities.

The most relevant application fields in terms of the number of projects initiated are Smart Mobility, Smart Governance, and Smart Metering & Grid. In Italy, there has been significant interest in the latter. In the Smart Mobility sector, solutions such as MaaS (Mobility as a Service), traffic management, the introduction of electric vehicles, and sharing services are essential for improving urban mobility and reducing

emissions. The growing importance of digitizing public administrations and using digital twins in Smart Governance allows for more effective and targeted urban planning, improving public service efficiency and citizen participation. Smart Metering & Grid, focusing on optimizing electricity through smart meters, sensors, and artificial intelligence, has seen particular growth in recent years thanks to EU projects on Positive Energy Districts. These developments indicate that Italy and Europe are investing in technologies that not only improve energy efficiency but also contribute to greater environmental sustainability.

Another interesting finding is Italy's central role in the smart city domain, alongside important countries like Spain, Germany, and Finland, which have shown a significantly higher number of projects compared to other countries. On a macro level, Western and Northern European countries have demonstrated greater commitment to these initiatives than Eastern European countries. This suggests that more developed economies have greater resources and infrastructure to invest in smart cities. On a city level, Stockholm has proven to be the smartest in Europe, followed by Milan, Helsinki, and Dublin. Milan's presence in this ranking is consistent with its role as Italy's economic center, followed by Rome, which also showed a good number of projects. This data indicates that economically stronger cities tend to be more advanced in smart city implementations, benefiting from resource availability and a greater ability to attract investments.

Economically, at the European level, it is evident that the public sector is heavily involved in funding projects, followed by a growing percentage of public-private partnerships. This suggests that the public component is essential, as it tends to consider returns in terms of welfare rather than profits. In Italy, the private sector has played a more significant role, demonstrating strong interest in smart city projects. The European Union has been a key player, funding 40% of the projects in the databases through various programmes. Most of the investments from framework programmes like Horizon Europe and Horizon 2020 have been directed towards Smart Metering & Grid, clearly indicating the direction the EU intends to pursue. In Italy, the role of the PNRR (National Recovery and Resilience Plan) has been crucial, providing extensive resources for Mobility, Smart Building, and Smart Metering & Grid, in line with the fund's missions 1, 2, and 5. These funding dynamics highlight how public support and strategic partnerships are essential for the progress of smart cities.

The fundamental technologies for implementing smart city projects have been the Internet of Things and Artificial Intelligence. IoT, representing 36% of applications, is essential for real-time data collection and management, confirming to be the backbone enabling technology of a smart city, while AI, covering 29%, is crucial for automating and optimizing operations in various domains, from traffic management to energy distribution. These data confirm that the combination of IoT and AI is the main driver of smart city innovations, enabling efficient and intelligent management of urban

resources. Specifically, in the coming years, it is reasonable to expect continuous growth in the application and integration of AI, which is nowadays the key technology on a productivity point of view.

Environmental sustainability and citizen well-being have been the most frequently achieved benefits, present in 72% of the projects. This focus reflects a widespread commitment to sustainability and reducing CO2 emissions. About 50% of projects emphasized improving citizen well-being and health, demonstrating a comprehensive approach to enhancing the quality of life in urban areas. These results indicate that smart cities aim to make cities not only smarter but also more livable and healthier for their inhabitants, namely what is encompassed in many definitions provided by the existent literature.

The use and valorization of data have played a crucial role in smart city projects, with a significant portion of data used to provide services to citizens towards prescriptive data valorization. Probably in the next year the adaptive data valorization mode will increase, thanks to the increasing introduction of AI in various application fields indicating a move towards more dynamic and real-time decision-making processes. This underscores the importance of intelligent data management in improving urban efficiency and the quality of services offered to citizens.

Smart city projects have strongly aligned with the Sustainable Development Goals, particularly SDG 11 (Sustainable Cities and Communities) and SDG 3 (Good Health and Well-being), achieved in about 90% of the projects. Other frequently achieved goals include SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action), reflecting the technological and environmental focus of these initiatives. This alignment demonstrates that smart cities are significantly contributing to global sustainability and human development goals.

Finally, citizen engagement is becoming increasingly integral to smart city projects, with various tools such as workshops, mobile apps, and shared platforms facilitating active participation. This trend reflects the evolving concept of Smart Cities 3.0, where citizens play a central role in co-creating urban solutions. The analysis showed a steady increase in citizen engagement from 2021 to 2023, indicating a growing recognition of the importance of involving residents in decision-making processes. This suggests that the success of smart cities also depends on the ability to actively engage citizens, making them an integral part of the urban innovation process.

In conclusion, the analysis confirms that Italy and other European countries such as Spain, Germany, and Finland are playing a fundamental role in the development of smart cities, with significant commitment from both the public and private sectors. The European Union continues to be a key supporter, directing significant resources towards technological innovation and urban sustainability. These joint efforts are transforming cities into more sustainable, efficient, and livable environments for

citizens, significantly contributing to global sustainable development goals and improving urban quality of life.

Once the main findings from the thesis work have been summarized, it can be said that these have been able to comprehensively answer the research questions listed in *section 2.1* of the chapter on thesis methodology, providing a broad view on all facets of the smart city theme.

4.2. Limitations

The limitations of this thesis are closely linked to the creation of the database used to carry out the analyses and the existing database of the Smart City Observatory of the Polytechnic of Milano. One significant issue is related to the fact that the database only includes projects at the level of geographical Europe, with a predominance of Italian projects, constituting about 25% of the total. This is mainly due to the ease of conducting research in the native language, as well as the fact that the Observatory's resources have predominantly focused on the Italian territory.

Another critical limitation is the difficulty in obtaining data on the scale of investments. Often, the websites used for research did not have this information available. Notably, by the end of the database compilation, it was observed that 75% of the investment value data for the projects pertained solely to Italy. Moreover, when data for other European projects were available, they mostly came from large-scale projects promoted by the European Union, involving multiple cities and countries. To retain the usefulness of the data without losing its relevance, the investment value of the project was evenly divided among the various countries and cities involved. This approach allowed the inclusion of investment data but did not precisely allocate it to each entity participating in the project. The problem of data scarcity was not limited to investment figures but also extended to the technologies used. The research often failed to describe precisely what type of technology was employed in the projects. However, the distribution of data derived from the analysis of technologies aligned with what has been presented in the literature.

Another limitation of the thesis is that it only includes projects up to April 2024, because that is when the research ended. Therefore, it misses projects that might start later in the year. This has led to making guesses about what might happen for the rest of the year based on what occurred up to April.

Lastly, some countries like France and Denmark appear to have fewer projects compared to other economically robust and pioneering nations in terms of innovation and industry. This discrepancy could be attributed to a research bias rather than a lack of interest in promoting smart city projects in these countries. This aspect highlights

the potential need for a more balanced and comprehensive approach to studying smart city initiatives across different regions to ensure a more equitable representation in future research.

4.3. Future Directions

The analysis conducted in this thesis revealed an interesting composition of the projects contained within the databases: 50% are pilot projects, 45% are executive projects, and only 5% are in the preliminary analysis phase. This distribution indicates a growing interest in implementing smart solutions in cities, showcasing an approach that favors innovation and experimentation. Particularly, pilot projects represent a significant openness to new ideas and technologies and reflect a cautious approach, as they are on a limited scale and aimed at creating best practices to be disseminated across Europe. However, the substantial presence of executive projects, which have seen significant growth from 2020, from 48 projects to 83 in 2023, highlights also a marked interest in large-scale realizations. This is a very positive indicator that demonstrates how projects are becoming increasingly robust and are viewed as of common interest, with the concept of Smart City gaining more prominence and relevance. Specifically examining projects from the European Union in the last 4 years, a two-tiered structure over time is evident: initially, pilot projects are implemented in selected cities to test the effectiveness of the proposed technologies and solutions. This experimentation phase serves to gather valuable data and feedback on the efficiency of the implemented solutions. Subsequently, executive projects are launched, benefiting from the experiences and insights gained from the pilots, thus allowing a broader and more targeted dissemination of technologies that have proven successful and sustainable. This progression from pilot to executive projects illustrates a mature model of incremental implementation, where each phase sets the groundwork for the next, ensuring that innovations are not only technically feasible but also accepted by the community and integrable into existing infrastructures. Therefore, the future of smart cities seems to be heading towards an even more strategic and thoughtful expansion, with projects that not only adopt new technologies but integrate them to transform cities into smarter, more sustainable, and inclusive environments.

Additional insights about the future of smart city projects can be derived from the Horizon Europe Strategic Plan 2025-2027 promoted by the European Union, which primarily focuses on three key areas [117]:

- **Green Transition**: fight climate change with the goal of achieving zero carbon emissions by 2050.

- **Digital Transition**: emphasizes digital technologies to enhance European competitiveness, particularly with substantial investments in artificial intelligence to achieve excellence.
- **A more resilient, competitive, inclusive, and democratic Europe**: innovation in research and development supports sustainable growth, respects planetary limits, and enhances competitiveness. Additionally, promoting social inclusion and cultural diversity is crucial to support the green and digital transitions, while ensuring health, well-being, and fundamental rights within the EU, with a particular focus on the inclusion of refugees and migrants.

From this strategic vision, Horizon Europe aims to steer Europe towards greater resilience to climate change through innovations in the energy and mobility sectors, targeting climate neutrality. This initiative includes transitioning to zero-emission energy and transport systems, improving energy efficiency, and increasing the use of renewable energies while keeping energy economically accessible. The adoption of digital technologies and artificial intelligence is crucial for optimizing the management of urban resources and services, making cities more efficient and adaptable. Therefore, a significant growth in areas such as Smart Mobility and Smart Metering & Grid can be anticipated. Moreover, Horizon Europe promotes an inclusive and participatory approach to urban decision-making, suggesting a growing engagement of citizens in smart city projects in the coming years, as confirmed in the last 4 years analyzed in the thesis.

Focusing specifically on the thesis work, some suggestions to expand and enhance the research for future development are necessary. First of all, the database created for this thesis has mapped the current state of smart city projects in Europe and Italy, but its structure allows for future expansions of the study, focusing on various aspects. As mentioned earlier, both the observatory's database and the one created for this thesis focus exclusively on the European territory. Therefore, a first step could be to extend the research of projects globally, to understand if there are different trends and what types of projects receive the most attention. Additionally, continuing research at the European level by including more countries outside of Italy would provide a more balanced database in terms of project numbers.

Another suggestion for future research is to obtain as much investment data as possible, to have a less biased mapping towards Italy. Exploring the nature of public-private partnerships could be particularly interesting. Although this model is theoretically the most advantageous for financing smart city projects, allowing for the sharing of risks and benefits between parties, it is currently used less frequently than public investments alone. However, projects like "The Ellinikon" in 2024, which involved significant resources from various sources, show that the public-private partnership model is gaining importance. Therefore, understanding the evolution of financing methodologies could be a valuable point of interest for future studies.

Since the concept of smart cities is closely linked to enabling technologies, it will be interesting to see how available technologies evolve in the coming years, particularly IoT and AI, and whether new technologies emerge that allow for new types of applications. Finally, the theme of SDGs is becoming increasingly important in the smart city context. As highlighted by the analysis, reducing pollution and carbon footprint are primary goals to achieve by 2030. It will be interesting to see if this will lead to the introduction of projects that impact more SDGs than currently involved.

In conclusion, future research in the field of smart cities can greatly benefit from expanding the database, exploring financing dynamics, and observing technological evolution, while always keeping the goal of creating more sustainable, efficient, and livable cities for all citizens at the forefront.

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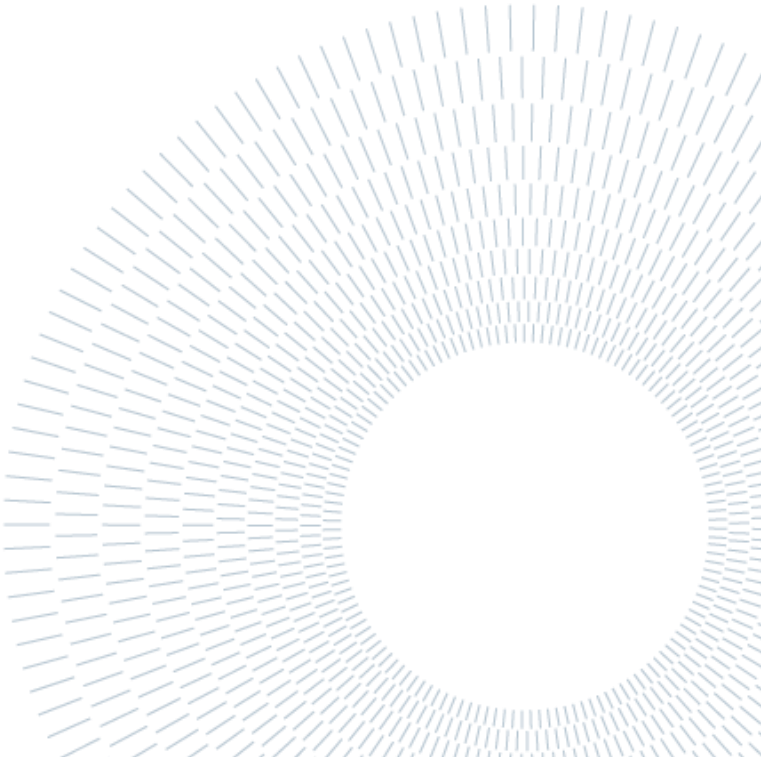
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