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SMART CITY PERFORMANCE MEASUREMENT SYSTEMS:

A NOVEL FRAMEWORK FOR ENERGY-RELATED PERFORMANCE

Master Dissertation of:

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Declaration

This dissertation is the result of the authors' own work and includes nothing which is the outcome of work done by others except as specified in the text.

The authors further state that no substantial part of their dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at Politecnico di Milano or any other University or similar institution.

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Sono giunto alla fine di un lungo percorso universitario iniziato 5 anni fa, durante il quale si sono susseguite innumerevoli sfide e ho potuto crescere come studente e come persona. Non sono mancati attimi di difficoltà o alcune piccole delusioni, ma i ricordi sono pieni soprattutto di momenti felici e di soddisfazioni personali e di gruppo, assieme alle tantissime persone che ho potuto conoscere e con le quali ho condiviso questi anni.

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Let today be a new beginning.

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Acronym	**Full name**
ACM	Association for Computing Machinery
AHP	Analytic Hierarchy Process
BCA	Building and Construction Authority
BEMS	Building energy management systems
BEV	Battery Electric vehicle
BOMA	Building Owners and Managers Association
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CESBA MED	Common European Sustainable Built Environment Assessment Mediterranean Area
CEUR	Central Europe
CH_4	Methane
CO	Carbon Oxide
CO_2	Carbon Dioxide
DE	Domestic Extraction
DGNB	German Sustainable Building Council
DMC	Domestic Material Consumption
DMI	Direct Material Input
DMP	Data Management Platforms
DSO	Distributor System Operators
EDEN	Energy Data Engagement
ESS	Energy Storage System
ESCI	Emerging and Sustainable Cities Initiatives
ESCo	Energy Service Company
EU	European Union
EV	Electric vehicle
FCEV	Fuel-Cell electric vehicle
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIEC	Gross inland energy consumption
GIS	Geographical Information Systems
GSE	Gestore dei Servizi Energetici
HEV	Hybrid electric vehicle

HFCs	hydrofluorocarbons
ICT	Information & Communication Technologies
IDB	Inter-American Development Bank
IFIP	International Federation for Information Processing
IOP	Institute of Physics
IoT	Internet of Things
ISO	International Organization for Standardization
ISTAT	Istituto Nazionale di Statistica
KPIs	Key Performance Indicators
LEED	Leadership in Energy and Environmental Design
LED	Light Emitting Diode
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
PCA	Principal Component Analysis
PFCs	Perfluorocarbons
PEC	Certified Electronic Mail
PHEV	Plug-in hybrid electric vehicle
PM	Particulate Matter
POCACITO	Pot-Carbon Cities of Tomorrow
POD	Point of Delivery
PPP	Power purchasing parity
REPLICATE	Renaissance of Places with Innovative Citizenship and Technology
RES	Renewable Energy Source
SETIS	Strategic Energy Technologies Information System
SF_6	Sulfur hexafluoride
SO_2	Sulfur dioxide
STEEP	System Thinking for Comprehensive City Efficient Energy Planning
SRS	Stockholm Royal Seaport
ST DEV	Standard Deviation
TSO	Transmission System Operators
UHI	Urban heat island
UN	United Nations
UK	United Kingdom
US$	United States Dollars
U4SSC	United for Smart Sustainable Cities
VEP	Voting Eligible Population
W2E	Waste to Energy

WHO	World Health Organization
ZEN	Zero Emission Neighborhood

ABSTRACT

Nowadays researchers agree that the first urban civilization labeled a ‘city’ was Sumer in c. 4500 BC. However, the meaning of the word has evolved over the years with the advancement of technology, and to reflect this evolution, adjectives such as digital, intelligent and smart have been prefixed to ‘city’. Today, population growth, rapid urbanization and climate change are triggering the need of smart city solutions and services. In 2050 global population is projected to reach approximately 9.8 billion people, and the 68% of us is expected to live in cities, compared to the today 56%. This will boost the number of people living in urban areas by 2.5 billion, meaning that we will have to build a new ‘Milan’ per week for the next thirty years. The incredible concentration of people, communities, activities, flows and impacts lead to sever challenges for cities. That is why the quite novel “smart city” topic is gaining more and more attention, becoming high on the agenda of many cities worldwide. In both planning and implementing smart city solutions, performance measurement is one key component. Nevertheless, and although they would like to do so, cities have not widely adopted or implemented such performance measurement systems yet. The aim of this work is to become a “facilitator” in this direction, providing City Authorities with an effective framework of key performance indicators (KPIs) focused on monitoring the evolution of a city towards an even smarter city. In doing this, the authors will focus on energy-related performances of the city, addressing the so-called “energy pillars”.

1 INTRODUCTION

The first chapter is the introduction of the work and it has two main objectives. First the concept of Smart City is introduced and described. It is important to properly define what is a Smart City, its pillars and the different typologies of Smart Cities because this is the scope of analysis of the thesis. The second goal is to assess the necessity of proposing a consistent Monitoring Framework for measuring the performance levels of a Smart City. This can be done defining appropriate Key Performance Indicators (KPIs). Today there is not a worldwide adopted framework of KPIs for Smart Cities and this existing issue constitutes the object of research.
Therefore chapter 1 is essential as (i) it introduces the work, providing the key concepts at the basis of the analysis and (ii) it lays the foundations for the research questions and objects that are developed in the following chapters.

The chapter begins with a description of the main trends that in recent years are transforming the society and the city. In this context the term Smart City emerges, and different definitions are provided and discussed. It is also reported the definition of Smart City according the authors of the thesis, with a description of the main characterized elements.

Then the Six Pillars that compose a Smart City are defined and explained. For each of them, the constituting elements are described, and the main challenges of today are discussed. Even though the scope of research is initially the Smart City in a comprehensive way, the research will be mainly focused just on pillars Smart Environment, Smart Living and Smart Mobility.

Furthermore, the different typologies of a Smart City are described, according to the way it is built, with related strengths and weaknesses. In particular there can be greenfield Smart Cities, built from scratch, or brownfield Smart Cities, which are existing cities implementing smart projects.

After that, the thesis introduces the need of defining a robust measuring framework for Smart Cities, through accurate Key Performance Indicators, and the main current challenges in monitoring city performances.

Finally, the two last sections present the questions and objectives of this work and the research methodology and thesis outline.

1.1 Smart city definitions and concepts

The worldwide population increase has led to a continuous transformation in the society and the lifestyle of habitants, mainly in **cities and urban areas**. Nowadays it is assessed that the resources of the planet are too limited to stand the actual demand and habits of final consumers. It is time for cities to shift towards more eco-efficient and sustainable models, in order to preserve actual natural and human ecosystems. (UN-Habitat 2016).

A relevant trend that is undoubtedly transforming the society is **digitalization**. Nowadays the outstanding development of digital technologies permits a higher data and information availability, which brings to a more efficient consumption and utilization of resources. Thanks to data analysis, IoT technologies and ICT tools, cities have the possibility to measure and control every service they provide to its dwellers and find new solutions and targets (Ibrahim et al. 2015).

Digitalization can be seen as an enabler of many sustainable and smart configurations that are emerging today: with digital technologies it is possible to adopt the prosumer-consumer configuration, in which different final energy users are connected one with the other in smart grids, micro grids or energy communities. This trend, also called **distributed energy generation**, is based on a bidirectional flow of energy between the final user and the grid, enabling cities to become more independent from the grid (Distributed Energy Systems 2016).

Digital technologies facilitate also **electrification**, because high-tech devices and smart meters permit efficient electricity utilization even with several loads connected simultaneously (lighting systems, air conditioning and refrigeration, E-vehicles charging station, etc.), increasing the level of performance and comfort inside a city (Gray 2017).

All these new trends which combine the exploitation of Information and Communication Technologies with the idea of creating a sustainable eco-system and increase urban quality of life, are included in the concept of **Smart City**. More precisely, a City is Smart when it uses digital technologies to implement systems and solutions that are efficient and sustainable in the long run, helping to face existing economic, environmental and social priorities and increasing citizens' quality of life (Hameed 2019).

The term Smart related to a city first appeared in the early 1990s, in relation to the concept of Digital City, when Internet adoption raised in everyday life (Dameri et al. 2013). The literature regarding this topic starts to increase in the firsts 2000, together with the growing attention to sustainability projects

and actions made at national or international scale, for example by the European Union. The number of publications has exponentially grown since 2010, when all the issues related resource scarcity and the population growth started to be clear and it was time to cope with them (Dameri et al. 2013).
During the years different **definitions** of Smart Cities has been adopted. Of course, Smart City is not a mathematical concept and therefore there is not a definition that can be considered as the most appropriate in absolute terms. Moreover, it also depends according to the perspective considered: cities are a complex system, in which several actors interact in different places and with different needs. Then, the definition of Smart City has to be the most comprehensive one, covering as many different aspects as possible. Some of the most meaningful ones are reported below.

Caragliu et al. 2011	"A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance"
Setis-Eu 2009	"Smart City is a city in which it can combine technologies as diverse as water recycling, advanced energy grids and mobile communications in order to reduce environmental impact and to offer its citizens better lives"
Bakıcı et al. 2013	"Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality."
Chen 2010	"Smart cities will take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone."
Zygiaris 2013	"A smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as green, intelligent, interconnected, innovative and knowledge cities."

Table 1- Smart City definitions

To mention few explanations of the smart city definition, according to the first definition provided by Caragliu et al. (2011), it is clear that, in order to be smart, cities need the effort of the governance in charge, that has to drive a sustainable and efficient solutions and increase of quality of life, through the right actions and investments. Of course, in order to guarantee better social conditions and the economic growth, also private citizens play a key role. This is why education and awareness of the actual smart plans and strategies have to be properly diffused, together with the right attitude and active involvement of each individual (Griggs et al. 2013).

In the definition provided by the European Commission (Setis-Eu 2009), there is more reference to the environmental aspects related to a city. Concepts such as circular economy, energy efficiency and resource optimization are cardinal in the Smart City idea. The attention for environment is clear since the problem of resources depletion and scarcity has risen in the recent years, and digital technologies can provide a wiser exploitation of each source. This will inevitably improve the life quality of citizens, certifying the link between environmental and social spheres (Lehni, F. 2000).

In the majority of the definitions reported, there is an indirect link with the six pillars of the Smart City: Smart Environment, Smart Mobility, Smart Living, Smart Economy, Smart People and Smart Governance (Zubizarreta et al. 2016). Their meaning, goals and challenges are explained more in detail in chapter 1.3.

Among the several existing definitions it is reported the following, that tries to summarize the key elements constituting the smart city paradigm and is provided by the authors of the thesis.

“The Smart City consists in a city which aims to face public and territorial problematics, through the utilization of solutions based on the adoption of ICT and digital technologies, involving a multiplicity of different stakeholders, through partnerships with the municipal bodies”.

Public themes can be summarized and represented by the **6 pillars.**

Technologies as **qualifying factors** to answer the smartness needs of the city

The multiplicity of stakeholders requires a **centralized coordination**

Smart City projects require the interaction and **participation of different stakeholders**

According to this definition, there are 4 main elements that constitute Smart Cities and that are highlighted with colours: Smart City Pillars, digital technologies, centralized coordination and participation among stakeholders. First of all, the Smart City approach is multidisciplinary and based on its 6 pillars: Smart Environment, Smart Mobility, Smart Living, Smart Economy, Smart People and Smart Governance. As previously said, they are explained in detail in section 1.3.

In order to enable the evolution of a City, the second relevant factor is the exploitation of digital technologies as a key success factor, since they are powerful tools that provide innovative and efficient solutions to overcome cities priorities and challenges.

The third element is centralized coordination: Smart City projects are complex as there is a large multiplicity and variety of actors involved, that are public authorities, local governments, private companies and single citizens. Therefore, centralized coordination is necessary: it is crucial to develop a robust and long-term plan that is comprehensive of all the Smart City pillars (Caragliu et al. 2011).

The cooperation and participation of the different stakeholders is the 4th element of Smart Cities and has to be guaranteed, since projects can have different sources and commitments but cannot be in trade off one with the other. For this reason, central coordination has to drive each project in a way that contributes to increase the City Smartness in its comprehensive view, without being in contrast with another project. In addition, Smart City development has to be punctually measured and evaluated with properly designed **Key Performance Indicators (KPIs)** (Caird et al. 2019).

1.2 Smart City Pillars

Smart City concept includes several different spheres, of which some are directly related to energy sources optimization and the environmental aspects, while others are more related to social and economic issues. According to the European Smart City Classification Standard (Giffinger et al. 2007), the smart City concept is made by **6 main Pillars**, which cover all the aspects related to a city. These dimensions are Smart Environment, Smart Mobility, Smart Living, Smart People, Smart Economy and Smart Governance, and they are explained in detail below (Zubizarreta 2016).

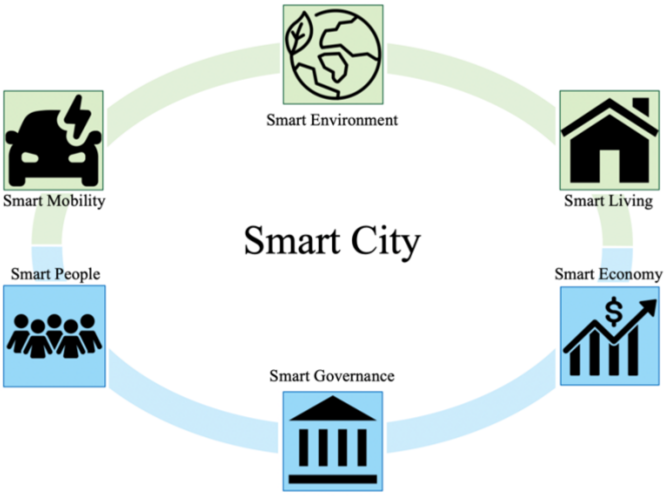


Figure 1- Smart City Pillars

Smart Environment: it is the growing attention to environmental sustainability of the city, through an efficient resource utilization and management system and acting against climate change, pollution, resource depletion. Practises such as clean energy consumption and material reuse and recycling are key factors in Smart Environment, together with the use of sensors, devices and smart applications that drive a wise and more optimal consumption of energy, water, soil and all other natural resources. Challenges related to Smart Environment are a more optimal exploitation of the city areas, in order to facilitate the rapid city growth, together with a more efficient use of resources, in line with their availability and scarcity in the long run (Hameed et al. 2019).

Smart Mobility: this pillar is focused on the promotion of sustainable transportation business models, that mainly concern electric or low emission vehicles, both private and public, autonomous driving, shared mobility, pedestrian and cycling routes. All of these solutions contribute to decrease pollution and emissions and raise local and international accessibility of the city in a sustainable and safe manner. A city is Smart in Mobility when it offers an efficient public transportation system, in line with actual citizens demand during peak hours, and smart ways for dwellers to have access to public and private transportation services, arising citizens quality of life and city attractiveness. Challenges connected to Smart Mobility are the diffusion of the propter infrastructure, such as charging stations for electric vehicles, the abundancy of sharing vehicles to cover the daily demand, the availability of pedestrian and cycling paths, the implementation of a road network that minimizes congestion, traffic and incidents and that facilitates the City growth (Zyryanov 2019; Pinna et al. 2017).

Smart Living: it is the adoption of smart and efficient solutions for public lighting around the city, the so-called Smart Lighting, and efficient heating and refrigeration systems for public and private buildings, namely Smart Building. The Smart Living concept is strictly linked with digital technologies since ICT solutions are enabler of the newest housing and industrial applications to limit and optimize energy consumption, thanks to smart meters and devices. Challenges connected to Smart Living for cities are the ability of improving the energetic class of a district without compromising its historical and/or artistical heritage, the equal distribution of wealthy among the different city areas, the fight against criminality (Baralas et al. 2019; Ambrogi et al. 2016).

Smart People: the key aspects of this dimension are the level of education and qualification of the citizens, the social, cultural and ethnic plurality, the open-mindedness and participation in public life and events. It is clear that the Population is the subject of the city and its effort and contribution is necessary in the development of a smarter city. Pro-active and qualified citizens facilitate the creation and success of new businesses, enhancing urban development, city attractiveness and equal distribution of wealthy among the different city areas. Aspects such as citizens health and security have to guaranteed and this is a big challenge for Smart Cities, together with society development, the creation of cultural identity, the availability and access to the newest technologies and the employment rate, often critical especially for young people (Allam et al. 2018).

Smart Economy: this pillar includes innovative spirit, entrepreneurship, productivity, labour market, economic wellness and growth. The development of a city that facilitates business progress and economic prosperity is at the basis of the application of the other pillars of a smart city. Budgets and investments of a City have to be addressed to innovative and sustainable business, finding profitable solutions in the long term. Digital technologies enable the implementation of new activities, indeed there is a wide space for start-ups and innovative businesses that can be a relevant source of progress and have to be sustained with the right funds and financial structure. Another challenge of Smart

Economy is the access of dwellers to infrastructures, services and technologies, that contribute to grow quality of life and attractiveness of the area (Zubizarreta 2016).

Smart Governance: local government strategies and actions affect the smartness of a city. In order to positively contribute to its development, social services and public participation have to be guaranteed and facilitated. Smart Governance is when there is a relevant presence of institutions and therefore various stakeholders are involved in decision making cycles and in the application of public services, facilitating connection between governments and citizens. Since there is a huge variety and amount of stakeholders involved in Smart City projects, a central coordination is essential in order to properly drive the different actions and efforts towards a unique effective solution. Institutions should also guarantee stability and longevity in their governance strategies, enabling profitable plans in the long run. The concept of e-governance, dealing with the use of ICT, is necessary to lead smart city plans to citizens, and to keep transparency in the decision and implementation process (Albino et al. 2015).

Among these six Pillars, Smart Environment, Smart Mobility and Smart Living are identified as "**energy pillars"**, since they are directly related with the process of "energy digitalization" in Smart Cities (Energy & Strategy Group 2019). "Digital energy" means the possibility of using digital technologies to control energy flows. In these pillars it is possible to implement digital and sustainable solutions such as Blockchain, IoT or Big Data and Analytics with the aim to optimize energy and resources, and to enable the current energy trends of distributed energy generation and electrification previously described (Gray 2017).
Instead, Smart People, Smart Economy and Smart Governance are considered as "non-energy pillars", since they are mainly connected with social and economic spheres. In the thesis the term "energy pillars" always refers to Smart Environment, Smart Mobility and Smart living while "non-energy pillars" refers to the other pillars.
Among all them, the work is more focused on the energy pillars, for which a deep analysis is developed. However, in order to have a comprehensive view of the Smart City concept, all its constituting elements are taken into consideration.

Of Course, there are often interconnections among these pillars, since there are aspects and concepts such as circular economy, or emissions coming from transportation, that are consequence of two or three pillars at the same time. This is because it is not a mathematical theory, but more an empirical vision that is quite common among experts and that the authors of the study adopt. However, there also have been found and analysed works and projects with different views, dividing the smart city concept in different categories, of which the most common are Energy, Society, Infrastructure and ICT. The authors decide to use the Six Pillars categorization because it is the most used and comprehensive view.

Interconnections between the 6 pillars can also make some actions unfeasible, because some interventions that would improve one dimension can negatively affect one other. As an example, a solution with large economic profit but also large environmental problems could not be considered a smart application (Zubizarreta et al. 2016). For this reason, it is always very important to adopt a comprehensive view in order to reach the highest level of smartness for a city.

1.3 Smart Cities typologies

Smart cities can be classified into two different typologies according to the way they are built:

- **Greenfield**: it is a completely new city created from scratch and characterized by a high level of smartness, i.e., a high utilization degree of digital solutions.
  Examples are the cities of Masdar (United Arab Emirates) and Songdo (South Korea). The former was built with a mix of public transportation and pedestrian/cycle areas that overcome the need of private cars, which will be deposited in park-and-ride outside the city. The latter, started in 2013 and expected to be finished in 2020, made great investments in electric vehicles, low carbon growth with export-oriented manufacturing and implemented an efficient waste management system that minimizes the need of human intervention (Han et al. 2018).

- **Brownfield**: it is built by the modification and transformation of existing cities through smart interventions with the aim of improving the life quality of citizens.
  Examples are the Boston Innovation District (Boston, United States of America), Lyon Smart Community (France) and Stockholm Royal Seaport (Sweden). The first succeeded in transforming the urban waterfront with opportunities for investments in collaborative technologies, sustainable growth and a shared economy. The second represents an example of efficient energy management by using solar power generation and introduction of smart energy devices for energy visualizations. Finally, in Stockholm were implemented several

projects to reduce carbon dioxide emissions and mitigate with future climate change strategies (Adapa 2018).

Different challenges are related to the two different typologies of Smart City. For sure, the greenfield alternative requires a higher organizational structure, as it is based on the idea of developing the city from zero. The focus on innovative planning through smart solution and digitalization requires large investments in information and communication technologies (ICT) for the development of new constructions (Hayat, P. 2016). Moreover, time required to design and implement the greenfield solution is often higher. Investments needed for this type of solution are so high that often make this alternative unfeasible, especially at large scale levels (Ibrahim et al 2015). This is why nowadays there are just few dislocated projects. However, ideally, greenfield cities represent a great opportunity to meticulously plan the city incorporating all desired attributes in an efficient manner.

On the other hand, brownfield alternatives often present issues in the coordination among projects, as they require meticulous retrofitting and reinforcement of the existing areas (Adapa 2018). Actually, the implementation of a brownfield solution has to harmonically fit with the city history and development. In addition, some brownfield projects are commissioned by private entities and citizens, that may do not consider the other interventions made in the same city. Therefore, a central coordination is fundamental, in order to guarantee synergies among interventions and reach a higher level of smartness at the whole city level. As positive attribute, brownfield projects usually imply lower investments compared to the greenfield ones.

1.4 Smart City Performance Measurement System

In order to speed up the wide scale deployment of smart city solutions, it is fundamental to facilitate and enable stakeholders in city projects to create trust in solutions, learn from each other and monitor progresses. In both planning and implementing smart city solutions, **performance measurement** is one key component. Thus, a set of standardized indicators is necessary to provide a uniform approach to what is measured and how that measurement is to be undertaken.

The purpose of building a **Key Performance Indicators (KPIs) framework** is to keep continuous track of interventions to answer questions on project progress, to understand whether the intended result has been achieved or something could have been done differently and to undertake countermeasures if necessary.

This enables the overall projects assessment and a successful communication of results. In particular, the smart city indicators equally have two primary target groups. The first group of stakeholders are decision makers in city council, who need to assess the impact of their smart city strategy over time, to understand if and how the city has become smarter and what has been the target outcome. The second group of stakeholders are national governments and European bodies, that verify whether their smart city policies reached specific goals (e.g., reducing energy use and greenhouse gas emission, increasing citizens participation, etc.) and tend to use indicators to compare cities.

Despite the abundance of KPI frameworks proposed by the literature, today there is not a worldwide adopted performance measurement system for Smart Cities, that can be considered an international standard. In this introductive chapter there is an exhaustive explanation of the main challenges for cities in implementing smart city monitoring solutions.

1.4.1 Challenges in monitoring Smart City

The great challenge for smart cities in monitoring their performances is represented by data and ICT platforms to be managed. Today there is a big opportunity to collect and report precise data thanks to the huge amount of information available from different networks around cities. However, the huge amount of data to be handled in order to implement the indicators implies the need of relevant digital strategies to be implemented in measurement and monitoring systems.

In particular, the collection and utilization of data coming from cities’ sources is not a linear and easy activity. Indeed, it presents many criticalities:

- **Information management**: the first problem regards the actors responsible for the different gathering and analysis phases. In fact, they must be organized as a unique entity, or, if more than one, they must be coordinated.
- **Interoperability**: several issues are related to the data interoperability, namely the possibility to realize simplified and standardized processes and an efficient data fruition.
- **Heterogeneity of data**: collected data are often heterogenous. This causes a reduction in the speed of analysis and a lower usability at community level, subsequently requiring additional steps for data cleaning. Thus, it’s fundamental to standardize the processes of data provision and guarantee continuity in their collection and recording.
- **Speed**: the capability to analyze and extract values from data rapidly represents a problem, especially in case of real time services.

- **Privacy**: one of the most discussed themes at city level. The ability to guarantee privacy and security of data concerning the applications dedicated to the city is certainly a priority.
- **Accessibility**: in order to extract values from data, it is not sufficient to just collect them, but they must be made available to providers who are responsible to offer services and information to the final user. If cities don't share gathered data, the only entity with the possibility to develop services, provided that there are resources and capabilities to do that, remains the municipality.
- **Open data**: in order to provide services to citizens and firms, it is favorable that information and collected data are accessible and available to all data users. For instance, data on energy consumption of final users (at the POD) might be made available to firms, in particular to ESCo, which offer energy efficiency services to citizens, firms and public administration (Energy & Strategy Group 2019).

The fact that the urban ecosystem can be monitored in all its aspects opens the city to a broad range of opportunities, but also to new criticalities in terms of information access and utilization, for both aggregated and singular procedures. Thus, the platform management within a city introduce some issues to be considered:

- **Integration among data sources**: before starting to manage data, it is necessary to set up the interconnection among sources. The final objective is to maintain a constant transmission of data from different sources. To do that, it is mandatory that all sources satisfied system requirements and were compatible with each other.
- **Data governance**: administration of data and planning of smart cities' development activities. Collecting systems of data return information, but cities are still unable to deal with governance and analysis since the shocking amount of data generated by IoT devices.
- **Platform scalability**: the higher the possibility of scaling and resizing, the better the platforms for data analysis in terms of operative functioning. One of the most effective solutions for DMP scalability is to use a cloud storage.
- **Data storage**: data must be stored in a secure way. The most feasible solution is the preservation of data in the cloud storage.
- **Cybersecurity of data**: it fundamental to guarantee the security of data and analysis carried out inside the platforms to avoid the possibility to compromise the reliability of data, quantifiable in losses of several millions.
- **Platforms interoperability**: in case the city had adapted more platforms to manage different problems, it usually faces issues related to the interoperability, namely the capacity of two or

> more networks, systems, devices, applications or components to exchange information, according to arranged request-response sequences, sharing their meaning, and to use them in a simple, safe and effective way, minimizing the inconveniences for the user (Energy & Strategy Group 2019).

A deep investigation of the current challenges in monitoring smart cities reveals that, in addition to the common issues regarding data management, there are also challenges related to monitoring specific aspects of a Smart City. Their identification and investigation are fundamental for a complete identification of the whole set of KPIs composing a pillar, guaranteeing a higher level of detail of the analysis.

One very discussed "aspect-specific" analysis regards city logistics and transportation systems. It concerns the transition to meet the targets set by the European Union strategy of reducing greenhouse gas emissions (European Commission 2011). The construction of propter mobility KPIs is fundamental to enable the shift towards a sustainable transport system, especially for the implementation of effective policies for low-emission vehicles, shared mobility and cycling and pedestrian paths. Then, a recurrent challenge in developing countries is the development of a sustainable road maintenance and management system that can be measured and monitored (Giret et al. 2018, Zyrianov 2019, Kamil et al. 2014).

City wastes is often a critical topic to address. In many countries, municipal waste management systems and urban waste heat recovery systems are still very poor. Thus, adequate selected indicators are powerful tools for the efficacy of investments in alternative solutions to meeting sustainable development goals and highlight the emergency and the need of intervention for a more sustainable environment and society (Da Silva et al. 2019, Andrés et al. 2018).

Finally, it is important to mention other specific aspects that might be missing in measurement systems. One regards the fact that smart cities innovative projects and measures should not be limited to a single building, but they should adopt a larger scale approach, trying to exploit potential synergies existing inside a district or among different ones (Genta et al. 2019).

Another issue is the lack of proper eco-innovation KPIs relative to certain sectors, which reduces the effectiveness of environmental regulations. For instance, one of those sectors is agriculture which is often missing in analysis (García-Granero et al. 2018).

1.5 Research Question and Objectives

Once defined the main existing challenges in measuring and monitoring Smart Cities, the authors assess the opportunity of contributing to the speeding up of wide-scale deployment of smart city solutions and services.

The object of this work is to construct a performance measurement and monitoring system for energy pillars of the Smart City, namely Smart Environment, Smart Living and Smart Mobility. In this framework, each energy pillar is classified in different subcategories, which refer to specific aspects of the pillar. The correct identification of the subcategories is fundamental, since they should provide a detailed level of analysis and facilitate the monitoring of the pillar in a comprehensive way.

In order to be effectively monitored, each subcategory should have appropriate Key Performance Indicators, which actually measure the performance of the city in the related subcategory and permit its stakeholders to keep track of the city progress and evaluate adequate strategies and actions for improving its level.

The aim of this work is to provide City Authorities an effective framework of Key Performance Indicators focused on monitoring the energy aspects of a city, facilitating its shift toward smarter solutions and models.

All the different sources analyzed contribute to provide the information needed to actually build a consistent framework.

1.6 Research Methodology & Thesis Outline

After this section, which describes Smart City concepts and research objectives, the second chapter introduces the literature review. It displays the frameworks analyzed, delineating the reasons for their investigations, the different methodologies for key performance indicators classification and the main gaps of literature that hamper the diffusion and applicability of the existing frameworks at global scale.

The third chapter shows the research questions of the work, which derive from the literature gaps identified in the previous chapter, and the theoretical framework proposed by the authors. The research questions have the objective of investigating on one or more gaps found from the literature. As an answer to the research questions, the authors present their conceptual framework for measuring and monitoring the energy pillars of Smart Cities, based on the literature review, with the definition of the subcategories that compose each energy pillar.

Once defined, the proposed theoretical framework is tested in chapter 4 across a broad group of empirical contributions that analyze specific energy aspects of a smart city and that cannot be found on the literature. In this way it is possible to assess the validity of the proposed theoretical framework, identifying possible changes and integrations in case additional Smart City aspects emerge from the empirical contributions.

After this integration with the empirical contributions, in chapter 5 a new comprehensive framework for measuring and monitoring energy pillars of Smart City is then built, with a reclassification of the subcategories included in each energy pillar and the punctual definition of the Key Performance Indicators, which are described in detail.

In chapter 6 the work furtherly includes the reporting of a survey developed by the authors of the work and addressed to the Italian cities, with the aim of assessing the relevance of the gaps identified from the literature: the survey investigates on the current main issues that emerge in the Italian context during the application of Smart City monitoring frameworks.

Finally, chapter 7 presents the findings and the overall results of the thesis, its theoretical and practical implications, its limits and the avenues of future research and analysis.

2 LITERATURE REVIEW

The second chapter is fully dedicated to the review of the extant literature. The aim of such an in-depth literature review is twofold. First it aims at identifying and analyzing the different frameworks and sets of key performance indicators found in literature in order to provide the reader with a thorough understanding of the theme, critically exploring its lights and shadows, without slipping into the trap of a misguided enthusiasm or an unfair criticism towards the existing frameworks. Second, by such a meticulous and broad review, the authors are able to properly locate the research problems, particularly highlighting the main problematics of the existing smart cities performance measurement systems that the authors aim to bridge.

Therefore, chapter 2 is a key component for the overall work as it (i) substantiates the existence and the importance of the limits raised by the authors and (ii) it serves as a fundamental examination of the theme to better specify the research focus and boundaries.

This chapter begins showing the sources of this step of the project and the procedure for searching them. After a deepened and targeted research, a large and diverse set of documents has been selected in order to have a perspective which was as broad as possible. This set, which forms the basis for the authors' first examination, is composed by some sources addressing more and different aspects of a smart city and some others focusing on specific ones.

Next, the chapter presents a deep analysis of the contributions, aimed at gathering all the information related to the frameworks and indicators examined. Particular attention was paid to the topics and themes observed going through smart city concepts and the features and specifics characterizing the indicators. The whole analysis was based on 37 contributions, presenting approximately 1292 KPIs.

Finally, the limits of these projects are explored in order to capture the main problematics of the existing smart cities performance measurement systems. This step was essential in order to understand what are the gaps that need to be bridged in order to improve the existing models. This lays the foundation for defining the objectives of the overall work.

2.1 Literature Contributions

The literature contributions have many different origins (e.g., articles, conference proceedings, books and book chapters). In particular, 17 of them examine different smart city aspects, while 20 are focused on one or two specific aspects of the city. It should be specified that the sectors in table X are indicated as displayed by the contributions, without any reference to the potentially adoptable taxonomies. In fact, that matter will be specifically discussed in the following section (2.2).

The background analysis was carried out querying an international database (Scopus), limiting the analysis to contributions published in English from the year 2000 onwards, and excluding areas of not interest. Moreover, the authors searched for additional relevant sources looking at the references and citations of the initial set of selected contributions.

The whole research generated 37 contributions. To identify the relevant ones for the literature analysis the authors adopted the following procedure. Further details are described in the Diagram below and in the Table.

1. Title analysis: the initial set of 3848 contributions were submitted to a title analysis. For this analysis, the authors performed a manual coding excluding the works presenting contents irrelevant for the authors' purpose. This led to the exclusion of 3184 contributions, and the identification of 664 ones eligible for the following abstract analysis.
2. Abstract analysis: this examination led to the exclusion of 566 out of 664, since the content of the abstract was not related to the smart city topics, thus they were deemed not consistent with the goal of the present research. Thus, a set of 98 contributions was obtained and considered suitable for the full text analysis.
3. Full text analysis: the full text analysis was fundamental in order to focus on those contributions that met the following criteria:
    a. Contributions providing a taxonomy for indicators/KPIs and/or
    b. Contributions providing a set of indicators/KPIs

These criteria led to the exclusion of 62 contribution and the authors obtained a final set of 36 contributions. After looking at the references and citations, 1 further contribution considered useful was added, for a total of 37 contributions obtained from the literature research.

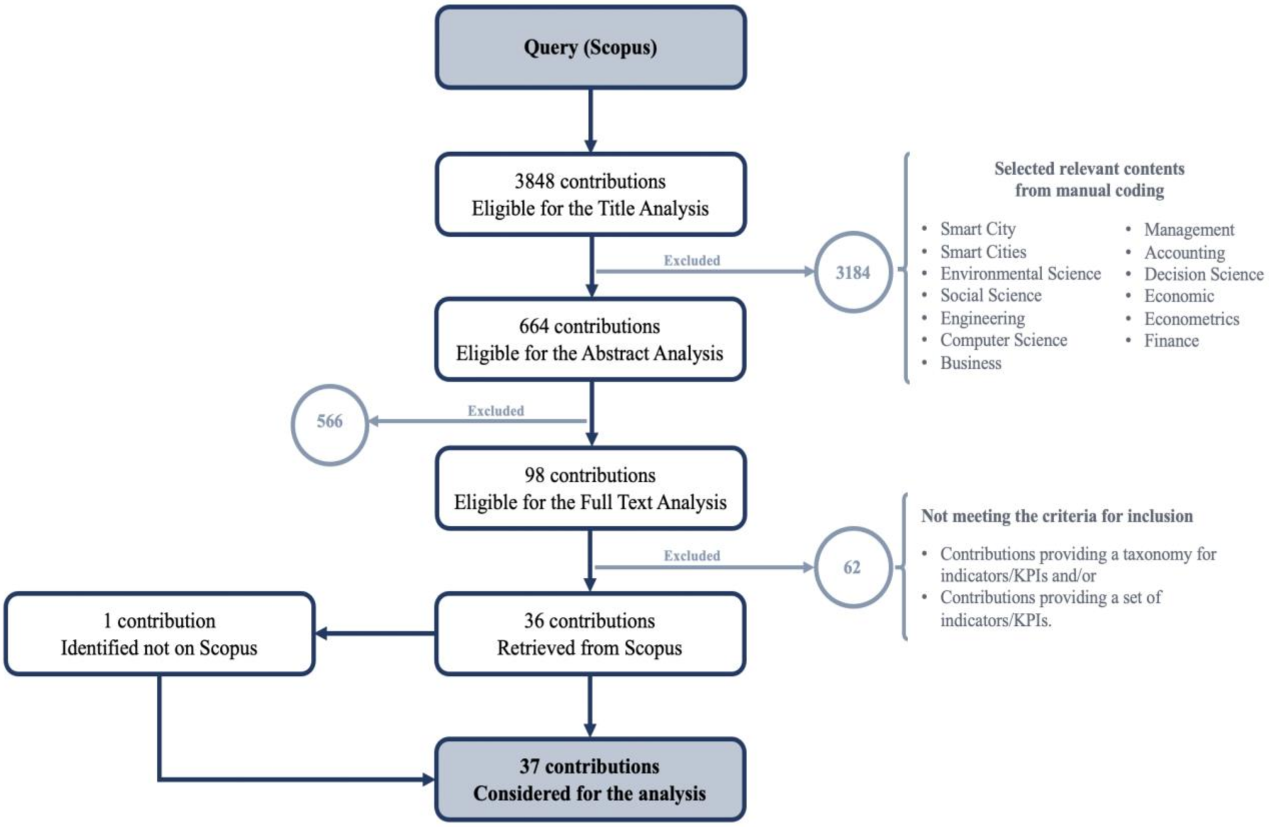


Figure 2- Procedure for the identification of the contributions to be included in the literature analysis

The table below illustrates the criteria selected for the literature review.

Criteria selection for the literature review				
Keywords	**Language**	**Publication Year**	**Areas**	**Exact Keywords**
TITLE-ABS-KEY ("framework" OR "model" OR "approach" OR "assessment" OR “measurement”) AND TITLE-ABS-KEY ("indicator" OR "KPI" OR "performance indicator" OR "metric") AND TITLE-ABS-KEY ("smart” OR “sustainable” OR “circular”) AND TITLE-ABS-KEY (cit*)	(LIMIT-TO (LANGUAGE, "English")	PUBYEAR > 1999	LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT- TO (SUBJAREA, "DECI")	LIMIT- TO (EXACTKEYWORD,"KPI") OR LIMIT-TO (EXACTKEYWORD, "KPIs") OR LIMIT-TO (EXACTKEYWORD, "KPIs (Key Performance Indicators)") OR LIMIT-TO (EXACTKEYWORD, "Key Performance Indicator") OR LIMIT-TO (EXACTKEYWORD, "Key Performance Indicators") OR LIMIT-TO (EXACTKEYWORD, "Key Performance Indicators (KPI)") OR LIMIT-TO (EXACTKEYWORD, "Key Performance Indicators (KPIs)")

	OR LIMIT-TO (SUBJAREA, "ECON")	OR LIMIT-TO (EXACTKEYWORD, "Key Success Factors") OR LIMIT- TO (EXACTKEYWORD, "Performance Assessment") OR LIMIT-TO (EXACTKEYWORD, "Performance Indicators") AND LIMIT-TO (EXACTKEYWORD, "Smart City") OR LIMIT-TO (EXACTKEYWORD, "Smart Cities")

Table 2 - Criteria selected for the literature review

The table below shows the literature contributions on which this first step of the analysis is based. For each contribution information about the following are provided: i) General information, in particular authors and date of publication, and source; ii) Theoretical development, in particular the context considered for the theoretical development (sector and geographical area) and the base for the development; iii) Indicators identified; iv) Empirical application, in particular the context considered for empirical application (sector and geographical area), the methodology used for the empirical application, the method used for the prioritization of the indicators.

Literature Contributions										
General information		**Theoretical development**					**Empirical application**			
Authors and date	**Title**	**Source**	**Sector**	**Geographical Area**	**Development based on**	**Indicators**	**Sector**	**Geographical Area**	**Method**	**Prioritization**
Kjendseth Wiik et al. 2019	A Norwegian zero emission neighborhood (ZEN) definition and a ZEN key performance indicator (KPI) tool	IOP Conference Series: Earth and Environmental Science	Zero emissions districts	Norway	Case study	32	District	Norway	Simulation	–
Shen et al. 2018	A holistic evaluation of smart city performance in the context of China	Journal of Cleaner Production	Different	China	Literature and interviews	18	Different	China	Case study	Entropy method
Genta et al 2019	Key Performance Indicators for Sustainable Urban Development: Case Study Approach	IOP Conference Series: Earth and Environmental Science	Different	Italy	CESBA MED and Delphi methods	14	Different	Italy	Case study	–
Androulaki et al. 2014	Proposing a Smart City Energy Assessment Framework linking local vision with data sets	5th International Conference on Information, Intelligence, Systems and Applications	Energy and environment	–	Existing frameworks	16	–	–	–	Weighting

Picioroaga et al. 2018	SMART CITY: Definition and Evaluation of Key Performance Indicators	10th International Conference and Expositions on Electrical and Power Engineering	Energy and environment	–	Literature	15	Energy and environment	–	Case study	AHP
Petrova-Antonova et al. 2018	Towards a technological platform for transparent and flexible assessment of smart cities	10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management	Different	Europe	Literature	89	Different	Bulgaria	Simulation	–
Korachi and Bounabat 2019	Towards a Platform for Defining and Evaluating Digital Strategies for Building Smart Cities	3rd International Conference on Smart Grid and Smart Cities	Different	–	Literature and existing frameworks	129	–	–	Simulation	Weighting and capability levels
Osella et al. 2016	Toward a Methodological Approach to Assess Public Value in Smart Cities	Public Administration and Information Technology	Different	Europe	Literature	41	Different	Italy	Case Study	Core and ancillary categorization
Carli et al. 2013	Measuring and managing the smartness of cities: A framework for classifying performance indicators	International Conference on Systems, Man, and Cybernetics	Different	Italy	Literature and case study	107	Different	Italy	Case study	Weighting
Sanchez et al. 2014	On the energy savings achieved through an internet of things enabled smart city trial	International Conference on Communications	Energy	Spain	Case study	4	Energy	Spain	Case study	–
Vasallo et al. 2019	The District Energy-Efficient Retrofitting of Torrelago (Laguna de Duero-Spain)	IOP Conference Series: Earth and Environmental Science	Energy efficiency	Spain	Case study	27	Energy efficiency	Spain	Case study	–
Balaras et al. 2019	Urban sustainability audits and ratings of the built environment	Energies	Buildings and built environment	Europe	CESBA MED	29	Buildings and built environment	Europe	Simulation	Normalization, weighting and aggregation
Ambrogi et al. 2016	Contributions from research projects on the Italian power system: Accountability of sustainable energy projects	International Annual Conference: Sustainable Development in the Mediterranean	Energy and Lightning	Italy	Existing framework	9	Energy and Lightning	Italy	Case study	–

		Area, Energy and ICT Networks of the Future2016								
Korachi and Bounabat 2019	Integrated methodological framework for smart city development	The International Conferences on ICT, Society and Human Beings, Connected Smart Cities and Web Based Communities and Social Media	Different	–	Literature	129	–	–	–	AHP
Shmelev and Shmeleva 2018	Global urban sustainability assessment: A multidimensional approach	Sustainable Development	Different	–	Existing frameworks	16	Different	–	Case study	Aggregation and weighting
Girardi and Temporelli 2017	Smartainability: A Methodology for Assessing the Sustainability of the Smart City	Energy Procedia	Energy and Mobility	Italy	Case study	36	Energy and Mobility	Italy	Case study	–
Mattoni et al. 2019	Towards the development of a smart district: The application of a holistic planning approach	Sustainable Cities and Society	Different	Italy	Literature	7	Different	Italy	Simulation	-
Da Silva et al. 2019	Sustainability indicators for urban solid waste management in large and medium-sized worldwide cities	Journal of Cleaner Production	Waste management	Brazil	Literature, surveys and national databases	49	Waste management	Brazil	Case study	–
Shahrokni et al. 2015	Implementing smart urban metabolism in the Stockholm Royal Seaport: Smart city SRS	Journal of Industrial Ecology	Energy	Sweden	Existing framework	26	Energy	Sweden	Case study and interviews	–
Andrés et al. 2018	Assessment methodology for urban excess heat recovery solutions in energy-efficient District Heating Networks	Energy Procedia	District	–	Literature and existing frameworks	28	–	–	–	–
Lopez-Carreiro and Monzon 2018	Evaluating sustainability and innovation of mobility patterns in Spanish cities.	Sustainable Cities and Society	Mobility	Spain	Literature	16	Mobility	Spain	Case study	Weighting

	Analysis by size and urban typology									
Clemente et al. 2019	Solutions and services for smart sustainable districts: Innovative key performance indicators to support transition	International Journal of Sustainable Energy Planning and Management	District	Europe	Case study	63	–	–	–	–
Giret et al. 2018	How to choose the greenest delivery plan: A framework to measure key performance indicators for sustainable urban logistics	IFIP Advances in Information and Communication Technology	Logistics	–	Case study	21	Logistics	–	–	–
Baralis et al. 2016	Analyzing air pollution on the urban environment	39th International Convention on Information and Communication Technology, Electronics and Microelectronics	Environment	Italy	Case study	14	Environment	Italy	Simulation	–
Weerakkody et al. 2012	Utilizing a high-definition live video platform to facilitate public service delivery	IFIP Advances in Information and Communication Technology	ICT	Europe	Case study	12	Different	Europe	–	–
Akande et al. 2019	The Lisbon ranking for smart sustainable cities in Europe	Sustainable Cities and Society	Different	Europe	Existing frameworks	15	Different	Europe	Interviews surveys and public national databases	PCA
Praharaj and Han 2019	Building a typology of the 100 smart cities in India	Smart and Sustainable Built Environment	Different	India	Literature and existing frameworks	54	Different	India	Case study	Discriminant function analysis
Pinna et al. 2017	Urban policies and mobility trends in Italian smart cities	Sustainability (Switzerland)	Mobility	Italy	Literature	10	Mobility	Italy	Case study	–
Zyryanov 2019	Methods for evaluation of mobility in modern cities	IOP Conference Series: Materials Science and Engineering	Mobility	–	Case study	13	Mobility	–	–	–
Acquaviva et al. 2015	Enhancing energy awareness through the analysis of thermal energy consumption	CEUR Workshop Proceedings	Buildings	Italy	EDEN	6	Buildings	Italy	Case study	–

Priano and Guerra 2014	A framework for measuring smart cities	ACM International Conference Proceeding Series	Different	Spain	Existing frameworks	9	Different	Spain	Case study	–
Kamil et al. 2014	A study to develop critical success factors of roads maintenance management system for sustainable facility management	Jurnal Teknologi (Sciences and Engineering)	Mobility	Indonesia	Survey	14	Mobility	Indonesia	Case study	Fuzzy-AHP
Yang et al. 2013	The technological integration of digital city and ecological city – take Sino-Finland Gongqing DigiEcoCity as an example	Advanced Materials Research	Different	China and Finland	Gongqing DigiEcoCity	30	Different	China and Finland	–	–
Pompei et al. 2018	Composite Indicators for Smart Campus: Data Analysis Method	International Conference on Environment and Electrical Engineering and Industrial and Commercial Power Systems Europe	District	Europe	Literature and existing frameworks	37	District	Italy	Case study	Weighting
Williams 2018	Eco-City Comparison: West versus East	Sustainability (United States)	Different	–	Literature	22	Different	UK and China	Case study	–
Hara et al. 2016	New key performance indicators for a smart sustainable city	Sustainability (Switzerland)	Different	Japan	Existing framework	52	Different	Japan	Case study	–
Artmann et al. 2019	How smart growth and green infrastructure can mutually support each other – A conceptual framework for compact and green cities	Ecological Indicators	Different	–	Literature	83	–	–	–	–

Table 3- Literature contributions

2.2 Contributions Analysis

As mentioned before, a detail analysis of the contribution in Table X led to the identification of about 1292 key performance indicators. The examined indicators stem from a broad set of approaches: literature (e.g., Picioroaga et al. 2018, Osella et al. 2016, Mattoni et al. 2019, Artmann et al. 2019), existing frameworks (e.g., Androulaki et al. 2014, Ambrogi et al. 2016, Shmelev and Shmelva 2018, Shahrokni et al. 2015), case studies (e.g., Kjendseth Wiik et al. 2019, Sanchez et al. 2014, Clemente et al. 2019, Giret et al. 2018), combined literature and existing frameworks (e.g., Korachi and Bounabat 2019, combined literature and interviews (Shen et al. 2019), combined CESBA MED and Delphi methods (Genta et al. 2019), surveys (Kamil et al. 2014) and others. The contributions analyzed also present different spotlights on geographical areas and methods for the empirical application. Regarding geographical area, the non-generic contributions address Norway (Kjendseth Wiik et al. 2019), China (Shen et al. 2019, Yang et al. 2013), Italy (e.g., Carli et al. 2013, Girardi and Temporelli 2017, Baralis et al. 2016, Pinna et al. 2017), Spain (e.g., Sanchez et al. 2014, Vasallo et al. 2019, Priano and Guerra 2014), Brazil (Da Silva et al. 2019), Sweden (Shahrokni et al. 2015), India (Praharaj and Han 2019), Indonesia (Kamil et al. 2014), Finland (Yang et al. 2013), Japan (Hara et al. 2016). With reference to the empirical application, the adopted methods are simulation (e.g., Petrova-Antonova et al. 2018, Baralas et al. 2019, Mattoni et al. 2019), case study (e.g., Vasallo et al. 2019, Pinna et al. 2017, Priano and Guerra 2014, Williams 2018, Kamil et al. 2014), combined case study and interviews (Shahrokni et al. 2015), and combined interviews, surveys and public national databases (Akande et al. 2019). Furthermore, some authors tried to prioritize the purposed key performance indicators. The methods used are different, such as the analytic hierarchy process (AHP) (Picioroaga et al. 2018, Korachi and Bounabat 2019), fuzzy-AHP (Kamil et al. 2014), principal component analysis (PCA) (Akande et al. 2019), entropy method (Shen et al. 2018), discriminant function analysis (Praharaj and Han 2019), normalization, aggregation and weighting (Balaras et al. 2019), weighting (Androulaki et al. 2014, Carli et al. 2013, Lopez-Carreiro and Monzon 2018, Pompei et al. 2018) and others.

The schemes analyzed are guided by a set of overarching goals that would characterize the assessment process and would specify the particular focus of the assessment schemes. In general, the dominant goal is to promote smart city development and enhance city competitiveness through the improvement of performance measurement systems.

The analyses presented in this section are developed in Microsoft Excel. It is important to understand that the authors first gathered all the data in order to create an entire dataset. In particular, the activity was carried out by recording all the specific details regarding the assessed schemes in a single excel sheet per each contribution. Therefore, each one is composed by the information that together constituted the backbone of the analyses presented in this section. Successively, the authors built different matrixes per each analysis, with rows corresponding to literature contributions and columns corresponding to the objects of interest. Given the complexity and the myriad of data, here are reported the main parts functional to the goals of this chapter, while extracts of the whole dataset are provided in Appendix XX.

The building blocks of any assessment scheme are key performance indicators that can be organized and classified in many different ways. In the examined contributions, indicators are clustered into one-, two- or three-tiered indicator systems. The two-tiered systems consist of ‘themes’ and ‘indicators’, the three-tiered ones also present an intermediary tier of ‘subthemes’ (i.e., the highest tier contains themes, the middle tier contains ‘subthemes’, and the lowest tier contains indicators). Themes can be defined as broad categories that connote major dimensions related to the objectives of smart city development. Each theme, in turn, can include several subthemes that provide further details to the themes themselves and delineate more specific targets that cities should strive to meet. Moreover, it can happen that some contributions addressing one specific smart city theme, such as Baralis et al. 2016, deploy only one tier describing indicators directly.

The research founded that approximately the 68%, 24% and 8% of the indicators systems are two-, three- and one-tiered respectively. Further details on tiers analysis can be found in the table below.

Contribution	**Number of tiers**		
	1	**2**	**3**
Kjendseth Wiik et al. 2019		X	
Shen et al. 2018		X	
Genta et al 2019		X	
Androulaki et al. 2014			X
Picioroaga et al. 2018		X	
Petrova-Antonova et al. 2018			X
Korachi and Bounabat 2019		X	
Osella et al. 2016		X	
Carli et al. 2013		X	
Sanchez et al. 2014	X		
Vasallo et al. 2019		X	
Balaras et al. 2019		X	
Ambrogi et al. 2016		X	
Korachi and Bounabat 2019			X
Shmelev and Shmeleva 2018		X	

Girardi and Temporelli 2017		X	
Mattoni et al. 2019		X	
Da Silva et al. 2019			X
Shahrokni et al. 2015	X		
Andrés et al. 2018		X	
Lopez-Carreiro and Monzon 2018		X	
Clemente et al. 2019			X
Giret et al. 2018		X	
Baralis et al. 2016	X		
Weerakkody et al. 2012		X	
Akande et al. 2019		X	
Praharaj and Han 2019		X	
Pinna et al. 2017			X
Zyryanov 2019		X	
Acquaviva et al. 2015		X	
Priano and Guerra 2014		X	
Kamil et al. 2014		X	
Yang et al. 2013		X	
Pompei et al. 2018			X
Williams 2018		X	
Hara et al. 2016			X
Artmann et al. 2019			X
TOTAL	3	25	9

Table 4 - Tiers analysis of the literature contributions

The table presents the observed results about themes used across schemes. It must be noticed that the fact that contributions present framework organized in different tiers led to some variety in analyzing themes. In fact, those adopting two tiers presented a higher number of themes with respect to those adopting three tiers since they organize the system with one tier less. Moreover, it must also be noticed that themes used across schemes, despite being part of the same layer, present different levels of specificity. In fact, many themes can be considered complementary or part of others and this must be considered in the creation of the theoretical framework presented in chapter 3. For example, air quality and GHG emissions themes can be considered under environment, or again, safety can be considered both under living and mobility. Thus, either this peculiarity derives from the city perspective or from the authors' interpretation of the phenomenon, it significantly increases the complexity of the analysis and must be further investigated in future works. Finally, in order to avoid bias in the whole examination and since the majority of the schemes adopted just two layers, further investigation on subthemes was not carried out. However, also that must be further examined in future works. Regarding the performed analysis, it can be noticed that there is a wide variation: 30 different themes were found, 4.2 are included, on average, in the selected schemes. To identify the most common ones, the authors calculated the frequency of appearance of each theme in the selected schemes. It is important to point out that different schemes use different terms to refer to the same or closely related themes. That is why, when it was necessary, the authors replaced certain terms with their synonyms to improve the accuracy of the process. For instance, the term “CO_2 emissions” was considered as “GHG emissions”, or the term “transportation” was replaced with “mobility” when found. Further details on the analysis are presented in Table X.

	No of themes	**Mean**	**Median**	**Max**	**Min**	**St. Dev.**
Themes	30	4.22	4.00	10.00	1.00	2.12
Most Common	Environment, Economy, Living, Mobility, Governance, People, Energy					

Table 5 - Outlook of the themes present in the literature

Themes	**%**
Environment	72
Economy	66
Living	34
Mobility	34
Governance	31
People	31
Energy	34
Infrastructure	19
Air Quality	16
Building	16
Access to services	13
Society	13
GHG Emissions	13
Education	13
ICT	13
Health	9
Urban Systems	9
Land and Material Resources	6
Innovation	6
Social Cohesion/Inclusion	6
Safety	6
Security	3
Waste	3
Water	3
Technical	3
Satisfaction	3
Family-friendliness	3
Traffic	3

Natural Resources	3
Culture	3

Table 6 – Most common themes in the literature

Once the most commonly used themes were identified, the documents were examined to count the indicators related to each theme and gather all the information provided by authors concerning the KPIs presented. As shown in the table below, the number of key performance indicators proposed presents great variance, ranging from a minimum of 4 to a maximum of 129, with an average of about 35.

	Mean	**Median**	**Max**	**Min**	**St. Dev.**
Indicators	34.92	22.00	129.00	4.00	33.10

Table 7- Outlook of the indicators per each literature contribution

Since the broad boundaries of the most common themes, the authors carried out a preliminary screen in order to aggregate all the existing indicators within environment, economy, governance, mobility, people and living to see which ones were the more persistent indicators according to the initial set of contributions. The only exception was made for the energy theme, which was not included indeed: this is due to the fact that its frequent presence was determined by a high number of studies focusing on that specific aspect as can be noticed from the Table X.

The environment theme is considered in all the contributions that address two or more different sectors. It accounts for the highest number of KPIs analyzed: approximately 355 indicators out of the 1292 KPIs deriving from contributions. After environment, living and economy are the ones with the second and third highest number of KPIs analyzed. In fact, they account for about 300 and 255 indicators respectively. Then, the authors' analysis led to the examination of almost 150 mobility key performance indicators, and 130 indicators related to the people theme. The theme accounting for the lowest number of KPIs analyzed is governance. In fact, about 105 indicators out of 1292 were found belonging to it.

Finally, it was fundamental to register also the different information characterizing the KPIs presented in the examined schemes. In particular, an in-depth analysis provided information about the following: i) Data owner; ii) Type of data (i.e., subjective or objective, quantitative or qualitative); iii) Relevance of the indicator (i.e., core or support/ancillary, extended or basic); iv) Perimeter of analysis (i.e., district, city, cities, etc.); v) Description of the KPI; vi) Frequency of reporting; viii) Unit of measure. Further details on the analysis are presented in table X.

Feature	**%**	**Feature**	**%**
Data Owner	32.4	KPI Description	16.21
Data Type	70.3	Frequency of Reporting	13.5
KPI Relevance	10.8	KPI Mode of Calculation	18.9
Perimeter of Analysis	86.5	Unit of Measure	64.9

Table 8 - Percentage of KPI information reporting in literature contributions

Approximately one third of the contributions identify a potential or actual owner of the data, about the 65-70% describe the type of data and the unit of measure of the indicator. Moreover, about the 86% of the examined schemes present the perimeter of analysis for which the set has been built. Instead, a really low percentage of contributions present an accurate and thorough description of the KPI and the procedure for its calculation. Finally, rarely the rate at which the KPI must be updated is accounted in the analyzed sets (less than 15%) and only in the 10% of the cases the authors presented a clear reference to the relevance of the indicator.

Contribution	**Data owner**	**Data type**	**KPI Relevance**	**Perimeter of Analysis**	**KPI Description**	**Update rate**	**KPI Mode of Calculation**	**Unit of Measure**
Kjendseth Wiik et al. 2019	X	X		X			X	X
Shen et al. 2018		X		X				X
Genta et al 2019		X		X				X
Androulaki et al. 2014		X						X
Picioroaga et al. 2018		X	X	X				X
Petrova-Antonova et al. 2018				X	X			
Korachi and Bounabat 2019				X				
Osella et al. 2016		X	X	X				X
Carli et al. 2013	X	X		X		X		X
Sanchez et al. 2014		X		X				X
Vasallo et al. 2019	X			X				
Balaras et al. 2019		X		X			X	X
Ambrogi et al. 2016	X	X		X				X
Korachi and Bounabat 2019				X				
Shmelev and Shmeleva 2018	X	X		X				X
Girardi and Temporelli 2017		X		X				X
Mattoni et al. 2019		X		X	X		X	X
Da Silva et al. 2019	X	X		X		X		X
Shahrokni et al. 2015		X		X		X		X
Andrés et al. 2018			X	X				X
Lopez-Carreiro and Monzon 2018								X
Clemente et al. 2019	X			X				
Giret et al. 2018		X		X			X	
Baralis et al. 2016		X				X		X

Weerakkody et al. 2012							X	
Akande et al. 2019	X	X		X				X
Praharaj and Han 2019		X		X				
Pinna et al. 2017	X	X		X		X		
Zyryanov 2019				X				X
Acquaviva et al. 2015		X		X	X			
Priano and Guerra 2014	X						X	X
Kamil et al. 2014		X		X				
Yang et al. 2013	X	X		X	X			X
Pompei et al. 2018		X	X	X	X			
Williams 2018		X		X	X			X
Hara et al. 2016	X	X		X				
Artmann et al. 2019				X			X	X

Table 9 - KPI information reported per each literature contribution

2.3 Literature Gaps

For each paper of literature analysed, the authors have identified the limits of analysis and the avenues of future research highlighted by the authors. This step has been very important for the authors' work, since they represent the gaps of literature that nowadays are still unsolved and that the authors aim to bridge.

In this section the authors report the relevant limits emerging from existing literature. 7 different categories of limits have been identified, which are system completeness, KPIs design, range/scale of application, data collection and availability, KPIs testing, and stakeholders involvement. All these categories are described below, with appropriate reference to the papers that highlight each specific limit.

System Completeness: one of the main limits regards the inappropriate framework completeness revealed by 10 authors. This is intended at two different levels. First, it concerns the insufficient identification of the appropriate number of areas of the city that must be measured and monitored. Then, the proposed indicators result not sufficient for the themes identified and missing for those that must be integrated for a comprehensive framework able to provide an accurate picture of city performances. In the majority of the cases, there is the necessity of increasing areas and indicators since some information is missing. Vice versa, in other cases they must be revised because there is redundancy of data. Finally, considering this issue it must be pointed out as the authors report the need of compiling and reviewing themes and indicators on a temporal basis, ensuring the continuous improvement of the framework.

To mention few examples, Osella et al. 2016 and Andrés et al. 2018 denote a limited number of core indicators if compared to the expectations of policy makers and the idea to facilitate replication and comparability among cities. Ambrogi et al. 2016 underlines that renewable energy indicators are not sufficient, while Petrova-Antonova et al. 2018 reveals the need of indicators for land, safety and health categories. According to Da Silva et al. 2019, there is the need to include new indicators in the Brazilian waste management system. In Korachi and Bounabat 2019 the list of indicators cannot be regarded as final, since it can be modified on the basis of future assessments and tests.

KPIs Design: 9 out of the analysed papers report a lack of inadequate structure or design of the proposed KPIs. As highlighted by the analysed contributions, many issues may limit the applicability of an indicator. First of all, it can be due to some common peculiarities of indicators like the lack of details in its definition, such as the description, the methodology for calculation, the unit of measure, temporal and spatial boundaries or further specifications needed to facilitate replicability and application of the indicators. In particular, specific attention must be paid also to the issues of **subjectivity** and **redundancy of data**. Regarding the first, the fact that some KPIs are not fully implies that there may be a certain level of bias in measurement. This is very frequent when indicators are being evaluated on a qualitative scale, such as Likert scale, which affects the interpretation and reliability of data. Concerning the second, one or more KPIs may overlap with each other since they totally or partially lead to the same calculation/measurement of data. However, it can happen since different indicators have different levels of specification. Finally, a particular attention must be paid to the **time relevance**. The moment of measurement is fundamental for the comparability among different cities and to access changes and improvements of a city compared to past results. It is important to identify the precise temporal boundaries of the measure. A recurrent limit consists in the timeliness of the data, since information is often obsolete or disaggregated one with the other.

To mention some examples of indicator design limits, Kjendseth Wiik et al. 2019 reveals a lack of harmonization among indicators, with big differences in system boundaries of KPIs. Baralas et al. 2019 declares the need of reconsider some of its proposed indicators, adding some details in order to provide a more comprehensive definition of the measure and facilitate the comparison among different cities. In addition, according to Andrés et al. 2018, the energy indicators need further specifications in order to address the main topic thoroughly. Another example is Osella et al. 2016 highlights this gap and underlines the need of a structured data repository for different time series.

Range/Scale of Application: 11 papers recognise the difficulty in applying the indicators on a larger number of cities and/or on a different scale. Some of the analysed frameworks are specifically designed for a single region, since they leverage on case-study approaches. For this reason, their

applicability at worldwide scale has not been demonstrated yet. This limit is due to the fact that each performance measurement framework is affected by some context specific factors. In fact, it must be noted that some parameters, such as the national peculiarities, the geographical area and the size, inevitably influence the strategy of cities. Therefore, to assess the feasibility and the chances of success of frameworks, some background parameters should also be considered.
Examples are Shen et al. 2018 which is focused on Chinese smart city programs, or Genta et al. 2019, in which indicators are properly selected for the city of Turin. Genta et al. 2018 also reports the need of adopting a model of KPIs that allows the measurement on a larger scale, shifting from the district to the city scale. On the other side, Androulaki et al. 2014 suggests that, as avenue of further research, the framework designed for the evaluation of the city as a whole, can be also customized per sector, such as municipal buildings, providing more focused information. Balaras et al. 2019 highlight the need to extend the range of application to other regions to facilitate and improve the effectiveness and the impact of action plans and policies.

Data Collection and Availability: 8 papers report the inability of collecting all the data and information needed for measuring the proposed indicators. This can happen for many different reasons such as very specific uses, detailed calculation required and so on. Moreover, in some cases data are available but still inaccurate. In other cases, data are not even available because they are not collected by the cities. These issues are really frequent, especially in less developed cities.
For instance, Da Silva et al. 2019 was only able to measure 11 out of the 49 indicators in its framework when it was tested in three Brazilian cities, showing difficulties regarding the availability of information in databases and reveal the need of drafting precise guidelines for management and data collection by local governments. Also, Shahrokni et al. 2015 has encountered many difficulties in collection data from owners and integrate them into its system during the testing of the framework.

KPIs Testing: 7 papers recognise limitations in the testing of the proposed framework of KPIs. Some of them has not been tested yet, therefore their application may be not immediate. Other frameworks are tested only in few near cities and the authors point out the need to expand the testing to other contexts. It must be noticed how this limit presents large room for improvement. In fact, as highlighted by the contributions, frameworks should be tested in a more and more large number of cities and/or projects in order to gather as many results and feedbacks as possible.
Examples are Korachi and Bounabat 2019 which points out that the KPIs still have to be assessed in real contexts. Lopez-Carreiro and Monzon 2018 tested its framework only in Spanish cities and identifies as a future line of research, the implementation of the framework in a larger set of cities.

Stakeholders Involvement: the application and the creation of a smart city framework requires the involvement of municipalities, as they are the practitioners, and the necessity of an incredible network of coordination among those latter, as it is reported in 3 papers analysed. Thus, for the correct functioning of the developed system, a systematic and continuous collaboration with stakeholders represents a fundamental prerogative. Moreover, it is fundamental also the presence of a central coordination to address different interventions towards single precise goals. The stakeholders involvement issue is more frequent in less developed countries, for example in Brazil, as Da Silva et al. 2019 reports.

Gap	**Contributions**
System Completeness	Kjendseth Wiik et al. 2019; Genta et al 2019; Petrova-Antonova et al. 2018; Osella et al. 2016; Ambrogi et al. 2016; Korachi and Bounabat 2019; Girardi and Temporelli 2017; Da Silva et al. 2019; Andrés et al. 2018; Giret et al. 2018.
KPIs Design	Kjendseth Wiik et al. 2019; Genta et al 2019; Balaras et al. 2019; Korachi and Bounabat 2019; Andrés et al. 2018; Weerakkody et al. 2012; Pinna et al. 2017; Hara et al. 2016; Osella et al. 2016.
Range/Scale of Application	Shen et al. 2018; Genta et al 2019; Androulaki et al. 2014; Osella et al. 2016; Balaras et al. 2019; Girardi and Temporelli 2017; Shahrokni et al. 2015; Clemente et al. 2019; Praharaj and Han 2019; Zyryanov 2019; Priano and Guerra 2014.
Data Collection and Availability	Shen et al. 2018; Osella et al. 2016; Mattoni et al. 2019; Da Silva et al. 2019; Shahrokni et al. 2015; Pinna et al. 2017; Hara et al. 2016; Artmann et al. 2019.

KPIs Testing	Kjendseth Wiik et al. 2019; Petrova-Antonova et al. 2018; Korachi and Bounabat 2019; Andrés et al. 2018; Lopez-Carreiro and Monzon 2018; Giret et al. 2018; Artmann et al. 2019.
Stakeholders Involvement	Mattoni et al. 2019; Da Silva et al. 2019; Weerakkody et al. 2012.

Table 10 - Gaps of literature

The review enables the authors to identify the main gaps of existing literature in measuring and monitoring frameworks for Smart Cities. The recognition of existing literature gaps is fundamental for the overall work since, starting from one or more of these gaps, the authors can develop the research question of their dissertation, investigating in how to deal with an existing issue and how to contribute to the literature research regarding this theme. The research question brings the authors to build up a propter theoretical framework for Smart Cities and propose it as an answer to the literature gaps. The proposed theoretical framework and its objectives are showed in the next chapter.

3 THEORETICAL FRAMEWORK

In the previous chapter, the authors explored the vast territory of performance measurement systems presented in the literature. In doing this, an extensive examination of all the features composing those frameworks was presented. Finally, the chapter was concluded with an in-depth analysis of the gaps characterizing the assessed schemes. The acquired in-depth knowledge of the whole, raised fundamental points to be investigated by the authors, who discovered the need of a new performance measurement system able to address the gaps identified.
Therefore, this chapter is fundamental since (i) it clarifies the research questions and objectives and (ii) presents the framework proposed by the authors.

First, the chapter recall the objectives of this framework and its main features such as the overall structure and the key performance indicators.

Successively, it focuses on the structure of the framework describing the areas to classification of the indicators and the rationale behind it. The subdivision layers are presented and defined to provide a comprehensive view of the framework.

Finally, the appropriate considerations regarding key performance indicators are done, presenting the framework results. Moreover, a brief evaluation is introduced in order to prepare the reader for the next chapter aimed at testing the proposed framework.

This chapter presents the initial theoretical framework constructed by the authors. Let’s rewind the journey that led to the definition of this framework. First, it should be recalled that the authors portrayed the incredibly vast concept of smart city, describing its facets, the main challenges of a city and the importance of a performance measurement system. Intrigued by such themes, particularly by the latter, the authors deep dived into smart cities literature. The result of such diving experience gave birth to chapter 2, where the features characterizing a performance measurement system are extensively explained. This led the authors to finally define the research objective. Stemming from the experience reported by the literature works, which especially highlighted the importance and centrality of the topic for the city transition towards a smarter version of itself, and from the gaps identified, there is a clear need for a new framework for the evaluation and monitoring of smart cities performances. The whole project represents the attempt to construct a performance measurement system that supports the speeding up of wide-scale deployment of smart city solutions and services in order to create impact on major societal challenges around the climate strategies and targets and the continuous growth and densification of cities. Therefore, this work aims to create a continuous improvement process through which cities are facilitated in learn from each other, create trust in solutions, and monitor progress, by means of a common integrated performance measurement framework. In particular, it must be specified what are the gaps that the framework aims to address and what are the potentials improvement that will be presented. Looking at the six main gaps found in literature, some considerations must be done. Since the framework has a theoretical origin, the range/scale of application, data collection and availability, KPIs testing and stakeholders involvement could not be addressed. Thus, it could target the system completeness and the KPIs design. However, as it is extensively explained in section 3.2, it was not possible to provide a set of indicators. That is why the goal of this initial theoretical framework is to improve the **system completeness** at the level of city areas that must be identified.

It must be noted that the progression of the areas and indicators is a clear prerogative for the framework. Thus, city areas forming the framework classification and key performance indicators must be formulated in such a way that they can be integrated in the city’s plan for gathering regular statistics. The outcome of the whole process, in turn, should get a regular place in the planning processes of the city. Another consideration that must be done before introducing the structure of the framework is that some parameters, such as the national peculiarities, the geographical area and the size, inevitably influence the strategy of cities. Therefore, to assess the feasibility and the chances of success of the proposed measurement system, some background parameters should also be considered.

3.1 Framework Structure

This section aims at defining the structure of the framework, in order to understand how it has been designed and conceived. First of all, the analysis presented in chapter 2 provided the authors a database composed by 37 assessed schemes, accounting for 1292 key performance indicators. Here, it is described how KPIs have been arranged and classified, while in the next section (3.2) a specific focus on indicators will be provided.

The evaluation framework has been subdivided in categories since it has a great advantage. In fact, it allows for a great flexibility, facilitating the identification of the city aspects and areas to be addressed and the subsequent creation of indicators that do not overlap with each other. As explained in chapter 1, this work is focused on the "energy pillars" of the smart city. The framework was organized in pillars (first layer) and subcategories (second layer). The definition of pillars and subcategories was carried out following the data regarding the 30 themes originated from the literature review. Stemming from those analyses, the majority of city areas have been derived from those already existing, reviewing the terms referring to them when necessary in order to provide clarity on the sector of impact. In addition, some new subcategories have been suggested in order to provide a complete system for performance measurement.

As described in the previous chapter the main themes employed in performance measurement systems are environment, economy, living, mobility, governance and people respectively. Thus, those consistent with the focus of this work, namely environment, living and economy are consequently adopted in the proposed framework. Moreover, the multitude of themes identified formed the basis for the definition of the second layer of subcategories of the framework. Next, the three pillars and the subcategories are defined to provide a clearer view of the framework structure.

3.1.1 Smart Environment

As reported in section 1.2, Smart Environment represents the growing attention to environmental sustainability of the city, through an efficient resource utilization and management system and acting against climate change, pollution, resource depletion. Practises such as recycling and clean energy consumption are key factors in Smart Environment, together with the use of sensors, devices and smart applications that drive a wise and more optimal consumption of energy, water, soil and all other natural resources. Challenges related to Smart Environment are a more optimal exploitation of the

city areas, in order to facilitate the rapid city growth, together with a more efficient use of resources, in line with their availability and scarcity in the long run.
The proposed theoretical framework identifies 8 subcategories that compose the pillar Smart Environment, in according to the need of guaranteeing system completeness to the framework, as it emerges from the literature.

The following subcategories were identified for the smart environment pillar:

- **Energy**: this subcategory aims at monitoring the energy production and consumption levels of the city, considering the different conventional sources (i.e., fossil fuels) for primary energy, the possible applications as secondary energy (e.g., electricity or thermal energy) and the final energy uses.
- **Energy – Green energy**: this subcategory aims at measuring and monitoring production and consumption levels of energy coming from renewable energy sources (RES). The authors decided to separate green energy from the previous subcategory (i.e., energy) in order to enhance the relevance of renewable sources in a Smart City, since their exploitation permits the distributed energy generation and more independence from the grid.
- **GHG Emissions**: this subcategory evaluates the level of greenhouse gases (GHG) emissions in the city. This is another very relevant theme in the current scenario, since the emissions lead to an increase in the average temperatures, causing dramatical climate and ecosystem changes. Today, the priority of reducing emissions levels is undoubtedly a common topic among national governments and international institutions, and cities are inevitably the place in which this shift has to occur.
- **Land and material resources**: this subcategory aims at measuring and monitoring the exploitation of the city natural resources, as soil, raw materials and green spaces. An important challenge for Smart Cities is to adopt an efficient exploitation of resources without compromising the city natural ecosystem and environment.
- **Pollution**: it refers to measure the level of pollutants such as O_3 and particulate matter concentrations, as PM2,5 and PM10 in the city. Air pollution is a recurrent aspect that cities are today trying to monitor and reduce, thanks to the newest technologies. A reduction in pollution would definitely arise citizens quality of life.
- **Waste:** this subcategory investigates on the city waste management system, evaluating the adoption and diffusion of material recycling solutions and other circular economy initiatives, that are drivers for more smart and sustainable cities.

- **Water**: it aims at monitoring the water management system in the city, accessing its efficiency and measuring water consumption levels. As land and material resources, water is a critical resource, and its exploitation has to be properly monitored and optimized.
- **Urban Planning**: this subcategory investigates on the city landscape, measuring the percentage areas dedicated respectively for households, commercial activities and for cultural, sport and leisure facilities. Moreover, the "unused" areas are object of evaluation.

Figure 3 - Subcategories of Smart Environment in the theoretical framework

3.1.2 Smart Living

The smart living pillar, as described in section 1.2, represents the adoption of smart and efficient solutions for public lighting around the city, the so-called Smart Lighting, and efficient heating and refrigeration systems for public and private buildings, namely Smart Building. The Smart Living concept is strictly linked with digital technologies since ICT solutions are enabler of the newest housing and industrial applications to limit and optimize energy consumption, thanks to smart meters and devices. Challenges connected to Smart Living for cities are the ability of improving the energetic class of a district without compromising its historical and/or artistical heritage, the equal distribution of wealthy among the different city areas, the fight against criminality.

In the proposed theoretical framework, the authors divide Smart Living in 6 subcategories, which should guarantee a comprehensive view of the pillar, in according to the gaps identified from the literature review.

The subcategories forming the pillar Smart Living are:

- **Building**: this subcategory aims at measuring the smartness of the buildings inside a city. Buildings are classified according to the type (residential, commercial or public) and the subcategory investigates on the adoption of smart devices and applications inside the buildings and their energy and resources consumption levels.
- **Access to services**: this subcategory is relevant as it investigates on the service offered by the city to its citizens, i.e., the availability of infrastructures that enable Smart City solutions, as diffusion of smart meters, accessibility, quality of the broadband services and availability of 5G connection and fibre-optic networks.
- **Public Lighting**: this subcategory refers to the evaluation of the public lighting system in the city, both for streets and for city squares. Object of analysis are electricity consumption levels for public lighting, quality of the service and the adoption of smart and technological solutions for increase the system efficiency.
- **Energy**: this subcategory evaluates the energy performances of the city in Smart Living aspects, in particular the diffusion of energy efficiency measures and applications in buildings and infrastructures, in order to optimize energy use.
- **Safety**: it investigates on the surveillance, control and automation infrastructures used in the city, both in public buildings and in outdoor areas.
- **ICT**: this subcategory aims at measuring and monitoring the diffusion of Information and Communication Technology platforms and solutions in the city, that are key drivers for increasing citizens quality of life.

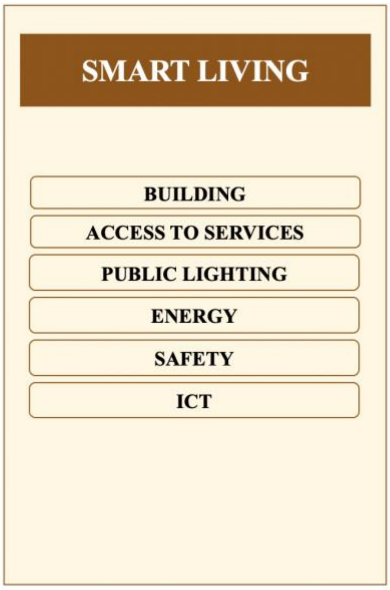


Figure 4 - Subcategories of Smart Living in the theoretical framework

3.1.3 Smart Mobility

As presented in section 1.2, this pillar is focused on the promotion of sustainable transportation business models, that mainly concern electric or low emission vehicles, both private and public, autonomous driving, shared mobility, pedestrian and cycling routes. All of these solutions contribute to decrease pollution and emissions and raise local and international accessibility of the city in a sustainable and safe manner. A city is Smart in Mobility when it offers an efficient public transportation system, in line with actual citizens demand during peak hours, and smart ways for dwellers to have access to public and private transportation services, arising citizens quality of life and city attractiveness. Challenges connected to Smart Mobility are the diffusion of the propter infrastructure, such as charging stations for electric vehicles, the abundancy of sharing vehicles to cover the daily demand, the availability of pedestrian and cycling paths, the implementation of a road network that minimizes congestion, traffic and incidents and that facilitates the City growth.

The authors identify 6 subcategories for Smart Mobility, which guarantee system completeness and a comprehensive examination of the pillar.

The subcategories forming Smart Mobility in the proposed theoretical framework are:

- **Public transportation**: this subcategory aims at measuring and monitoring the performances of the public transportation system of the city. In particular, it investigates on the number of different modes offered to citizens, the availability of different routes and the network connections among different city areas.
- **Private vehicles**: it aims at showing the overall profile of the city in terms of private cars that daily circulate across. In particular it investigates on the diffusion of low-emissions vehicles, as Hybrid Electric Vehicles (HEV) and electric vehicles, as Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV), which constitute the current e-mobility solutions. Electric mobility is one of the main solutions that are emerging today in the society, and its diffusion is no doubt fundamental in a Smart City.
- **Alternative transportation**: this subcategory aims at evaluating the diffusion of alternative mobility solutions to the conventional private vehicles and public transportation, which are the diffusion of car-pooling and sharing mobility, the availability of pedestrian and cycling routes, the possibility of use autonomous driving vehicles.
- **Mobility Infrastructure**: this subcategory investigates on the availability and diffusion of the infrastructure needed for enabling Smart Mobility solutions. In particular, infrastructures that are often very critical in the city are Electric vehicles (EV) public charging stations, which

permit the users to recharge the car in the middle of a travel, facing the recurrent problem of the limited autonomy of an electric vehicle.

- **Traffic**: it evaluates the traffic level across the different areas of the city, and the implementation of solutions for limiting congestions, as smart traffic lights, car free zones, real-time traffic monitoring systems, incentives in electric or sharing transportation.
- **Road Safety**: it considers the frequency of road accidents that happen in the city, both due to traffic congestion and for inadequate roads planning and maintenance.

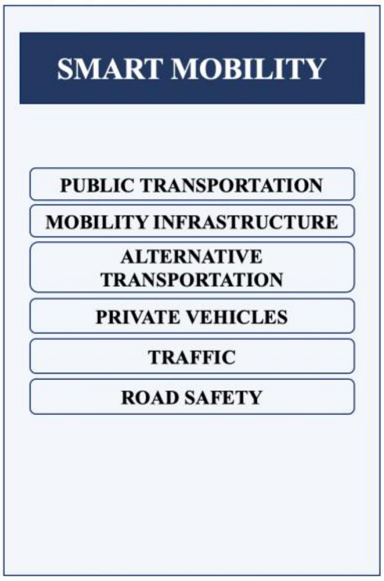


Figure 5 - Subcategories of Smart Mobility in the theoretical framework

The figure below provides a final picture of the framework.

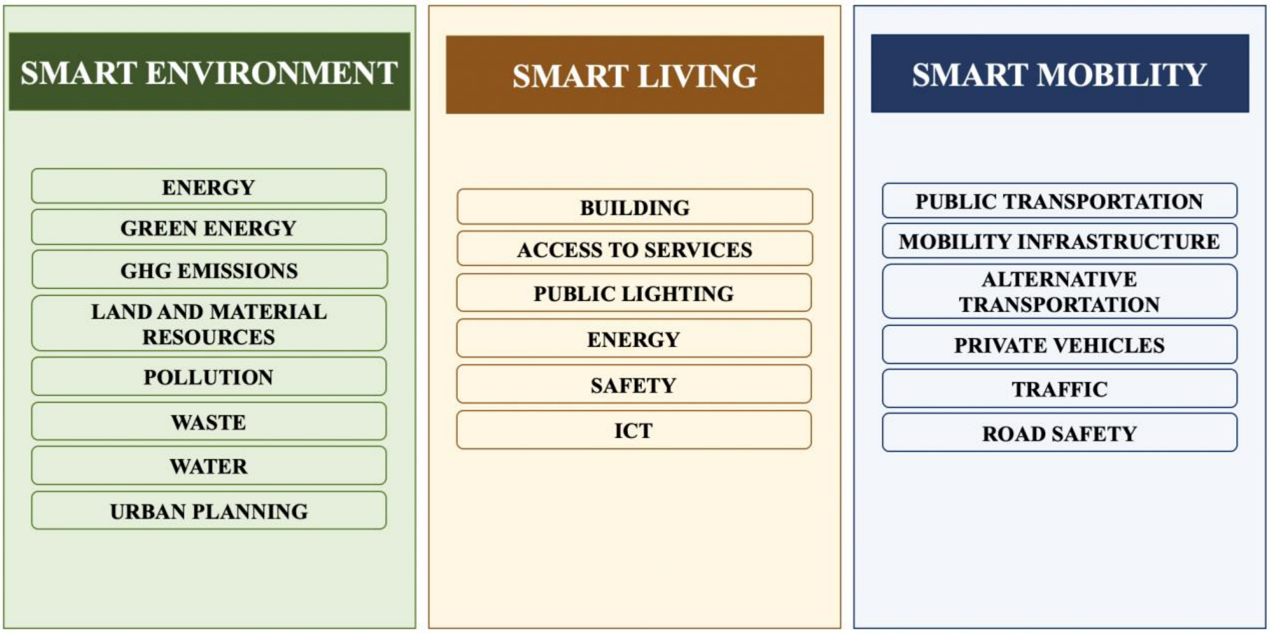


Figure 6 - Subcategories in the theoretical framework

3.2 Key Performance Indicators

As mentioned before, the overall analysis was based on about 1290 key performance indicators. After the preliminary screen described in section 2.2, about 780 could be considered as part of the smart environment, living and mobility pillars. However, in describing the indicators we must focus on the analysis presented in Table XX, also in section 2.2. According to the result obtained, it must be noticed the incredibly raw amount of data that the literature analysis provided to the authors. In fact, as extensively explained in chapter 2, a very little number of KPIs were defined in an acceptable way that could make them available for review and as a base for the creation of thorough indicators. Therefore, in absence of additional data, it could not be possible to create a set of indicators for now.

In particular, to provide the reader a comprehensive perspective on key performance indicators, they must be selected and/or constructed following a series of fundamental criteria aiming at proving their viability. It can be noticed that some are more general, while others appear also as gaps identified from literature. Here, we report an appropriate the set of criteria based on those recalled by the CITYkeys project (Bosch et al. 2017).

- Relevance: each indicator should have a significant role for the evaluation process and all the indicators should have a consistent relation to the subcategories of the framework. Moreover, the indicators should be defined in a way that the possible implementation of a smart city would provide an evident change of the indicator value.
- Completeness: the set of indicators should consider all the aspects of the energy related pillars. This is why categories and subcategories have been identified, and specific indicators have to be assessed for each subcategory in order to build a comprehensive framework.
- Availability: data for the indicators should be available and easy to be collected through the different sources of data. Indicators that require, for instance, interviews of users or dwellers are not suited as the large amounts of data needed are too expensive to gather. In case data availability for a specific indicator is difficult, it has to be specified and possible alternatives for the measurement can be evaluated (i.e., shifting the perimeter of analysis from city scale to national scale).
- Measurability: an indicator has to be easily measured in an objective way. For energy-related pillars, it should not be difficult to define quantitative and objective indicators.
- Reliability: the definition and the calculation method of each indicator should be clear and not open for different interpretations. This holds for the definition itself and for the calculation methods behind the indicator.

- Familiarity: each indicator should be easy to understand in by the users.
- Non-redundancy: indicators should not be overlap with each other, since they have to measure different aspects for the pillar.
- Independence: any change in an indicator should not have an impact in the evaluation (positive or negative) of other indicators of the framework.

3.3 Framework Evaluation

This brief final section aims at drawing the final considerations for the theoretical framework and paving the way for the next chapter that will presents the empirical analysis.

The objective of the work and the proposed framework are extensively presented in this chapter. As explained before, the framework presents a more complete construction in terms of areas of the city that need to be addressed. However, the advancements must be proved by the authors. That is why, the following steps are fundamental in order to provide a full understanding of the potentials for success and the results that can be obtained by the adoption of this framework. The natural consequence is a comprehensive test of the framework that the authors carried out in the next chapter. In fact, an empirical analysis is presented in order to understand to which extent the target gaps are bridged and what are the next possible development of the framework.

4 EMPIRICAL ANALYSIS

After having examined the contributions from literature, and presented the theoretical framework developed by the authors, the fourth chapter is focused on the empirical analysis aimed at testing the proposed framework. In fact, after building the theoretical framework, it must be tested in order to provide a full understanding of its potentials for success and the results that can be obtained by its adoption. In order to carry out this testing phase, the authors resort to the experience of the existing frameworks provided by the main international organizations. In fact, the selected contributions are projects and frameworks that have been developed by international institutions and organizations, that assess smart cities performance measurement systems and provide a comprehensive perspective on results obtained by testing them in wide and significant real scenarios.

The aim of such empirical analysis is twofold. Thus, chapter 3 is a key component for the overall work as it (i) answers the questions raised in the previous chapter, testing the proposed theoretical framework and (ii) it serves as a fundamental examination of the phenomenon in order to understand the next possible development of the framework for its improvement.

This chapter begins with the exhibit and a brief explanation of the contributions that form the basis of the empirical analysis, and the rationale behind the research of them.

Next, the chapter presents a deep analysis of the contributions, aimed at testing the theoretical framework, proving the consistency of its pillars and subcategories as well as the existence of other ones. Moreover, it provided significant information regarding indicators. The whole analysis was based on 17 contributions, presenting approximately 1320 KPIs. This validation phase lays the foundation for the next development of the authors’ framework.

Finally, the last section exhibits a discussion on additional information that provide the reader with a full picture of the empirical analysis.

4.1 Empirical frameworks

As described above, the contributions presented in this section are mainly projects and initiatives that have been developed by international institutions and organizations with the aim of assessing measurement frameworks that can be replicated globally (e.g., ISO 37120, developed by the International Organization for Standardization). The frameworks analysed have been sought taking into account the contributions published in English from the year 2000 onwards, from two different steps. First, through a series of web searches on Google, especially on the official sites of the organizations of interest. In this regard, the research keywords employed were “smart” or “sustainable” or “circular”; “city” or “cities”; "framework" or "model" or "approach" or "assessment" or “measurement” or “system”; “key performance indicator” or "KPI" or "performance indicator" or “indicator” or "metric". The second step of the research was based on a peculiar examination of the references of the previously examined literature contributions. The whole research led to the identification of 17 main contributions that were all considered viable for examination after the verification of three main criteria. First, the projects must address the smart city topics. Second and third, the projects must provide a taxonomy for indicators/KPIs and/or a set of indicators/KPIs.

The table below shows the contributions on which this analysis is based. For each contribution information about the following are provided: i) General information, in particular authors and date of publication, and source; ii) Geographical area; iii) Indicators identified.

Empirical contributions				
Author and date	**Title**	**Source**	**Geographical Area**	**Indicators**
Bosch et al. 2017	CITYkeys indicators for smart city projects and smart cities	–	Europe	76
International Organization for Standardization 2018	Sustainable cities and communities – Indicators for city services and quality of life (ISO 37120)	–	–	128
Hynes et al. 2019	D7.1 Approach and Methodology for Monitoring and Evaluation	Positive City ExChange	Europe	33
REPLICATE project 2017	D10.2 Report on indicators for monitoring at city level	REinassance of Places with Innovative Citizenship and Technology	Europe	56
UN-HABITAT	City Prosperity Index	UN-HABITAT	Ethiopia	52

2015				
STEEP project 2015	List of possible Key Performance Indicators	Systems Thinking for Comprehensive City Efficient Energy Planning	Europe	51
Smiciklas 2019	Key Performance Indicators for Smart Sustainable Cities	United for Smart Sustainable Cities (U4SSC)	–	110
Angelakoglou et al. 2019	A Methodological Framework for the Selection of Key Performance Indicators to Assess Smart City Solutions	Smart Cities	Europe	75
Bhada et al. 2009	Global City Indicators	–	–	74
International Organization for Standardization 2019	Sustainable cities and communities – Indicators for Smart Cities (ISO 37122)	–	–	80
Marijuán et al. 2017	Key Performance Indicators Guide	EU Smart Cities Information System	Europe	62
UN Statistical Commission 2020	Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development	The 2030 Agenda for Sustainable Development	–	14*
Inter-American Development Bank (IDB) 2013	Indicators of the Emerging and Sustainable Cities Initiative	Emerging and Sustainable Cities Initiative (ESCI)	Latin America and Caribbean	117
Economist Intelligence Unit 2014	European Green City Index	–	Europe	30
DGNB system 2018	DGNB system – New buildings criteria set	–	–	128
POCACITO 2014	Report on Key Performance Indicators	POCACITO	Europe	25
Eurostat 2004	Urban Audit	–	Europe	209

* The authors considered only those referring to the smart cities, according to the goal 11 of the agenda.

4.2 Testing the Theoretical Framework

This section, which is the key component of this chapter, presents a series of analysis aiming at validating the theoretical framework presented by the authors in chapter 3. Again, the analyses presented in this section are developed in Microsoft Excel. It is important to understand that the authors first gathered all the data in order to create an entire dataset. In particular, the activity was carried out by recording all the specific details regarding the assessed schemes in a single excel sheet per each contribution. Therefore, each one is composed by the information that together constituted the backbone of the analyses presented in this section. Successively, the authors built different matrixes per each analysis, with rows corresponding to literature contributions and columns corresponding to the objects of interest. Given the complexity and the myriad of data, here are reported the main parts functional to the goals of this chapter, while extracts of dataset are provided in Appendix XX.

The building blocks of any assessment scheme are key performance indicators that can be organized and classified in themes as described in chapter 2. The table X presents the observed results about themes used across schemes. Again, it must be noticed that the fact that contributions present framework organized in different tiers led to some variety in analyzing themes. In fact, those adopting two tiers presented a higher number of themes with respect to those adopting three tiers since they organize the system with one tier less. Moreover, it must also be noticed that themes used across schemes, despite being part of the same layer, present different levels of specificity. In fact, many themes can be considered complementary or part of others. Thus, either this peculiarity derives from the city perspective or from the authors' interpretation of the phenomenon, it significantly increases the complexity of the analysis and must be further investigated in future works. Finally, in order to avoid bias in the whole examination and since the high number of the schemes adopting just two layers, further investigation on subthemes was not carried out. However, also that must be further examined in future works. Regarding the performed analysis, it can be noticed that there is a wide variation: 41 different themes were found, 9.65 are included, on average, in the selected schemes. To identify the most common ones, the authors calculated the frequency of appearance of each theme in the selected schemes. It is important to point out that different schemes use different terms to refer to the same or closely related themes. That is why, as it has been done in the previous chapter, when it was necessary, certain terms have been replaced with their synonyms to improve the accuracy of the process. Additional information regarding the full analysis is shown in Table XX.

	No of themes	**Mean**	**Median**	**Max**	**Min**	**St. Dev.**
Themes	41	9.65	9.00	14.00	3.00	3.35
Most Common	Environment, Economy, Governance, Living, Mobility, People					

Themes	**%**
Environment	71
Economy	65
Governance	65
Living	65
Mobility	59
People	47
Pollution	41
Waste	41
Social	35
Water	35
Energy	35
Health	29
Education	29
ICT	29
GHG Emissions	24
Safety	24
Urban Planning	24
Finance	24
Technical	18
Traffic	18
Building	18
Building Energy	18
Employment	12
Alternative Mobility	12
Green Energy	12
Energy Efficiency	12
Culture	12
Water Management	12
Recreation	12
Public Lighting	6
Electricity	6
Food Security	6
Road Infrastructure	6
Road Safety	6
Prosperity	6
Demography	6
Security	6
Access to services	6
Telecommunication	6

Public Administration	6
Integrated Planning and Design	6

As can be noticed from the table above, a significant amount of information was identified in this analysis. In fact, it is fairly higher not only considering the overall number of themes identified, but especially considering the average number of themes presented per each framework. In fact, with respect to the literature review about 10 themes more have been distinguished and approximately 6 themes per framework more. The significance of the results obtained from this analysis is twofold. First, the authors were able to verify the quality of the theoretical framework proposed in the previous chapter, substantiating the importance of the categories defined after the literature review. In fact, all the 20 subcategories composing the framework have been identified with more or less similar terms referring to them. Second, these results allowed for a further investigation of themes in order to improve the existing framework.

Once the most commonly used themes were identified, the documents were examined in order to gather all the information provided by authors concerning the KPIs presented. A meticulous inspection of the contributions highlighted a more structured approach with respect to the previous schemes, characterized by a detailed construction of indicators, and providing a broader range of specific information. The authors initially reviewed the number of key performance indicators appearing in the contributions, that always address different aspects of the smart city. As mentioned before, a detail analysis led to the identification of 1320 key performance indicators, slightly more than in the previous literature analysis (about 1292). As shown in the table below, the number of key performance indicators proposed presents great variance, ranging from a minimum of 14 to a maximum of 209, with an average of about 78, which more than doubles that of the previous analysis (about 35).

	Mean	**Median**	**Max**	**Min**	**St. Dev.**
Indicators	77.65	74.00	209.00	14.00	48.81

Since the broad boundaries of the most common themes, the authors carried out a preliminary screen in order to aggregate all the existing indicators within environment, economy, governance, mobility, people and living to see which ones were the more persistent indicators according to the initial set of contributions. The environment theme is considered in all the contributions that address two or more different sectors. It accounts for the highest number of KPIs analyzed: approximately 365 indicators out of the 1320 KPIs deriving from contributions. After environment, economy and governance are the ones with the second and third highest number of KPIs analyzed. In fact, they account for about 315 and 240 indicators respectively. Then, the analysis led to the examination of almost 160 living key performance indicators, and 135 indicators related to the mobility theme. The theme accounting for the lowest number of KPIs analyzed is people. In fact, about 110 indicators out of 1320 were found belonging to it.

Successively, an in-depth analysis provided information about the following: i) Data owner; ii) Type of data (i.e., subjective or objective, quantitative or qualitative); iii) Relevance of the indicator (i.e., core or support/ancillary, extended or basic); iv) Perimeter of analysis (i.e., district, city, cities, etc.); v) Description of the KPI; vi) KPI Classification (i.e., if indicators were clustered in a three-tiered system); vii) Frequency of reporting; viii) Detailed explanation of the indicator calculation methodology; ix) Unit of measure; x) Strengths and weaknesses of the KPI; xi) KPI requirements (i.e., for reporting); xii) The rationale/interpretation under the existence and monitoring of the indicator; xiii) The set of additional information, such as the target and/or the benchmark of the KPI, the expected availability, expected accessibility, expected reliability, etc.; xiv) other notes and considerations regarding the indicator. Further details on the complete analysis are shown in Table XX.

Feature	**%**	**Feature**	**%**
Data Owner	100	KPI Mode of Calculation	76.47
Data Type	100	Unit of Measure	100
KPI Relevance	82.35	Strengths and Weaknesses	47.06
Perimeter of Analysis	100	KPI Requirements	52.94
KPI Description	88.24	Rationale/Interpretation	70.59
KPI Classification	47.06	Additional Information	70.59
Frequency of Reporting	88.24	Other Notes	35.29

As can be noticed from the table above, the amount of information available from this analysis is incredibly higher than that presented in chapter 2. All the frameworks report the data owner and type as well as the perimeter of analysis and the unit of measure. Approximately 88% of the time the frequency of reporting of indicators. Moreover, apart from the other relevant data, such as the strengths and weaknesses and the rationale, this examination shed light on fundamental information that are indispensable and on which the authors can rely in order to create a set of key performance indicators. In fact, about 80-90% of the assessed schemes thoroughly report the full KPI description and the methodology for its calculation.

Contribution	Data owner	Data type	KPI Relevance	Perimeter of Analysis	KPI Description	KPI Classification	Frequency of reporting	KPI Methodology of Calculation	Unit of Measure	Strenghts and weaknesses	KPI Requirements	Rationale/Interpretation	Additional information	Other Notes
Bosch et al. 2017	X	X	X	X	X	X	X	X	X	X	X	X	X	X
International Organization for Standardization 2018	X	X	X	X	X		X	X	X	X	X	X	X	
Hynes et al. 2019	X	X	X	X	X		X	X	X		X	X	X	X
REPLICATE project 2017	X	X		X	X	X	X	X	X		X		X	
UN-HABITAT 2015	X	X	X	X	X		X		X	X				X
STEEP project 2015	X	X	X	X	X	X			X	X				
Smiciklas 2019	X	X	X	X	X	X	X	X	X		X	X	X	
Angelakoglou et al. 2019	X	X	X	X	X				X				X	
Bhada et al. 2009	X	X	X	X	X		X	X	X	X	X	X	X	
International Organization for Standardization 2019	X	X	X	X	X		X	X	X	X	X	X	X	
Marijuán et al. 2017	X	X	X	X	X	X	X	X	X					
UN Statistical Commission 2020	X	X	X	X	X		X	X	X	X	X	X	X	X
Inter-American Development Bank (IDB) 2013	X	X		X	X	X	X	X	X			X	X	X
Economist Intelligence Unit 2014	X	X	X	X		X	X		X			X		
DGNB system 2018	X	X	X	X	X		X	X	X	X	X	X	X	X
POCACITO 2014	X	X		X	X	X	X	X	X			X		
Eurostat 2004	X	X	X	X			X	X	X			X	X	

The performed analyses were able to provide a full picture regarding the validation and the lack of the theoretical framework. In particular, stemming from those results, the authors were able to prove the consistency of the city areas identified and improve them by adding missing ones. Moreover, the information gathered on key performance indicators were fundamental in order to review the indicators collected in the literature review and create the authors’ own set of KPIs. The further development of the theoretical framework is presented in the next chapter, where its final version is displayed.

4.3 Discussion

As explained above, this chapter was fundamental to test the theoretical framework substantiating the city areas identified and their limits as well as providing additional data for further development. This last section presents some supplementary considerations that must be done in order to give the reader a full picture of the empirical analysis. In particular, what emerged are some detailed information that can be considered as avenues for future research since they shed light on specific issues regarding the design of key performance indicators and their availability.

Those issues are following described.

Incomplete Measure: the KPI isn't thorough and/or truthful since not all the dimensions or the wrong ones affecting the measurement are taken into account. This may imply different types of distortions in the outcome such as under or overestimation. For example:

- Accessibility of open data sets: quality of the data is only expressed as the openness and ease of use of data. Other aspects like accurate, available, complete, conformant, consistent, credible, processable, relevant, timely have not been taken into account (e.g., Bosch et al. 2017).
- Access to basic health care services: in order to truthfully measure the accessibility of basic health care facilities, measuring only the physical dimension of accessibility is not sufficient. The social (affordability of such services) and cultural barriers would have to be measured as well, if the 'full picture' is to be shown (e.g., Bosch et al. 2017).
- Percentage of city population living below the international poverty line: internationally, people living in extreme poverty is currently defined by the United Nations as those living on less than US$1,25 a day. Applying the current average persons per household figure to all households can lower distinctions between household size in poor and more affluent households, that is, it could have the effect of underestimating the actual number of people who live below the poverty line (e.g., International Organization for Standardization 2018).

Interpretation/Comparability: in some cases, the KPI is measured according to different cities' policies and rules/standards, or definitions. In may also happen that a KPI is rational only for some cities. This reduces the comparability. For example:

- Annual number of public transport trips: transport systems often serve entire metropolitan areas, and not just central cities. The use of number PT trips with origins in the city itself will capture many trips whose destination is outside the city but will generally capture the impact that the city has on the regional transport network (e.g., International Organization for Standardization 2018).

- Number of registered voters as a percentage of the voting age population: voting age population is not necessarily an exact measure of the number of citizens entitled to vote as it does not take into account legal or systemic barriers to the exercise of the franchise or account for non-eligible members of the population, such as resident non-citizens or in some jurisdictions persons serving a sentence of imprisonment in a penal or correctional institution (the voting eligible population (VEP) would capture these discrepancies but it is very hard to achieve the data required to measure VEP). However, in some countries, noncitizens, such as immigrants, have been granted the legal right to vote in municipal elections before they become citizens (e.g., International Organization for Standardization 2018).
- Percentage of population living in affordable housing: the threshold figure is based on a percentage a household spends on housing relative to overall income. The specific percentage will change based on local regulations and standards regarding housing affordability. For example, in Canada the housing affordability threshold is surpassed when a household spends more than 30 % of its income on housing. In France, the threshold is 40 % (e.g., International Organization for Standardization (2018).

Recall Error: some errors are caused by differences in the accuracy or completeness of data retrieved. This can occur when study participants are asked to recall events or experiences from the past. It usually happens in surveys, interviews, questionnaires and so on. An example is:

- Under age five mortality: estimates based on household surveys data shall be obtained: a) directly, using birth history, as in demographic and health surveys; or b) indirectly, using the Brass method, as specified in the Multiple Indicator Cluster Surveys. In developing countries, household surveys are essential to the calculation of this indicator, but there are some limits to their quality. Survey data are subject to recall error, and surveys estimating under-5 deaths require large samples, because such incidences are uncommon and representative households cannot ordinarily be identified by the sampling. (e.g., International Organization for Standardization 2018).

5 PERFORMANCE MEASUREMENT FRAMEWORK

Exploring the vast territory of performance measurement systems presented in the literature (chapter 2), proposing the initial theoretical frameworks (chapter 3) and successively testing and validating its effectiveness and problems through the analysis of the main international frameworks, allowed the authors to gain an-in depth understanding of the phenomenon under scrutiny. Hence, the authors were able to improve the previously built framework and are now prepared to describe its final version of the framework which aims to get back to and eventually answer in a more exhaustive way the research question posed in Chapter 1.

First, the chapter recall the objectives of this framework and its main features such as the overall structure, the key performance indicators and the primary target groups.

Successively, it focuses on the structure of the framework describing the classification of the indicators and the rationale behind it. The subdivision layers are presented and defined to provide a comprehensive view of the framework.

Then, the entire process of definition of key performance indicators is described together with their specific features. In addition, a complete overview of the constructed framework is proposed.

Finally, the last considerations regarding the framework are done, briefly portraying the current status of the work and prepare the reader for the next chapter aimed at investigating the context specific factors characterizing the Italian picture.

This chapter presents the last version of the framework constructed by the authors. Let's rewind the journey that led to its definition. First, it should be recalled that the authors portrayed the incredibly vast concept of smart city, describing its facets, the main challenges of a city and the importance of a performance measurement system. Intrigued by such themes, particularly by the latter, the authors deep dived into smart cities literature. The result of such diving experience gave birth to chapter 2, where the features characterizing a performance measurement system are extensively explained. This led the authors to finally define the research objective. Stemming from the experience reported by the literature works, which especially highlighted the importance and centrality of the topic for the city transition towards a smarter version of itself, and from the gaps identified, a clear need for a new framework for the evaluation and monitoring of smart cities performances has been identified. This led the authors to create the initial theoretical framework (chapter 3), which has been successively tested in chapter 4 through the experiences of the existing frameworks built by the main international institutions and organizations in order to validate its ability to bridge the literature gaps and investigate its further development. The whole process showed the way for the realization of the final version of the performance measurement framework proposed by the authors. As described before, the whole work represents the attempt to construct a performance measurement system that supports the speeding up of wide-scale deployment of smart city solutions and services in order to create impact on major societal challenges around the climate strategies and targets and the continuous growth and densification of cities. Therefore, this work aims to create a continuous improvement process through which cities are facilitated in learn from each other, create trust in solutions, and monitor progress, by means of a common integrated performance measurement framework. In particular, it must be specified what are the gaps that the framework aims to address, reviewed according to the findings emerged from the empirical analysis. Looking at the six main gaps found in literature, some considerations must be done. Unfortunately, as it will be explained in section 5.4, the authors were not able to test this framework on the Italian panorama. Therefore, the range/scale of application, data collection and availability, KPIs testing could not be addressed while some improvements were done in terms of involvement of stakeholders, in particular municipalities. Thus, the final framework is proposed in order to target the **system completeness** and the **KPIs design**. First, the system completeness is finally targeted at both levels. Stemming from the theoretical framework and the data obtained from the empirical analysis, the authors were able to improve the set of areas that must be accounted in assessing the city performances. Subsequently, the key performance indicators describing those categories have been constructed. Second, a comprehensive set of KPIs has been designed. Particular attention was also paid to the time relevance, subjectivity and overlapping issues. In fact, indicators provide a clear definition of time boundaries of measurement, are defined in order to be measured in a fully objective way. Concerning the overlapping issues, despite the definition ensures no overlapping between two or more indicators, complete independence in measurement must be proved by testing it on a real scenario since it can happen that some could lead to the same measurement of data, at least partially. The same consideration must be done for the additional challenge of incomplete measure identified in the empirical analysis. Finally, it was not possible to address the interpretation/comparability and recall error challenges, again, found in the empirical analysis. The full description of the framework is portrayed later in this chapter.

The proposed framework, and in particular, the constructed key performance indicators, aim at serving decision marking. This latter encompasses different decision makers at various levels of the process. Thus, the presented indicators, have two main target groups:

- Decision makers at city level who must design the smart city strategy over time. This group has also the responsibility to monitor the city transition and answer the question has the city become smarter by critically analyzing the final results.
- National governments and other bodies (e.g., European ones), that must design the smart city policies. It has also the responsibility to monitor the effect of their smart city policies on the overall attention to the designated targets. In addition, it uses indicators to compare cities.

As explained previously, it must be noted that the progression of indicators is a clear prerogative for the users just indicated. Thus, key performance indicators must be formulated in such a way that they can be integrated in the city’s plan for gathering regular statistics. The outcome of the indicator process, in turn, should get a regular place in the planning processes of the city. Of course, the proposed indicators could also be used by other groups of interest, such as educational institutions and businesses. Finally, for citizens the indicators may be powerful tools for understating the impacts of cities’ initiatives. Another consideration that must be done before introducing the structure of the framework is that some parameters, such as the national peculiarities, the geographical area and the size, inevitably influence the strategy of cities. Therefore, to assess the feasibility and the chances of success of the proposed measurement system, some background parameters should also be considered.

5.1 Framework Structure

This section aims at defining the structure of the framework, in order to understand how it has been designed and conceived. First of all, the analyses presented in chapter 2 and 3 provided the authors a database composed by 54 existing indicator frameworks, accounting for 2612 key performance indicators. Here, it is described how KPIs have been arranged and classified, while in the next section (5.2) a specific focus on indicators will be provided.

The evaluation framework has been subdivided in categories since it has a great advantage. In fact, it allows for a great flexibility, facilitating the identification of the city aspects and areas to be addressed and the subsequent creation of indicators that do not overlap with each other. As explained in chapter 1, this work is focused on the "energy pillars" of the smart city. The framework was organized in pillars (first layer) and subcategories (second layer). The definition of pillars and subcategories was carried out following the data regarding the 54 themes originated from the literature and empirical reviews, and from the information emerged from the survey of Italian cities. However, it must be noted that the full involvement of municipalities in designing the structure of the framework would have given a clearer understanding of cities targets and policies. This matter should be addressed in future works. Thus, the adopted pillars are smart environment, smart living and smart mobility, and they are presented briefly recalling the extensive definitions provided in chapter 1. The subcategories, which final version is presented later in this section, have been defined in two different steps. The first preliminary classification was partial and realized after the literature review. Instead, the final version was realized after the empirical review and the survey. Finally, different categories were defined in order to group together different clusters of subcategories, but it must not be considered a proper classification layer. Next, the three pillars and the subcategories are defined to provide a clearer view of the framework structure.

5.1.1 Smart Environment

As reported in section 1.2, Smart Environment looks at the environmental sustainability of the city, thanks to a wise exploitation of conventional energy sources, the integration with renewable energy sources (RES), the efficient use of resources such as water and soil and the waste reduction. The categories identified for this pillar are Energy, Ecosystem, Pollution, Waste and City Planning. Next the different subcategories aiming at comprehensively describe the smart environment pillar are described.

The following subcategories form the category Energy:

- **Energy – Electricity**: it includes indicators that analyse production and consumption levels of electric energy in the city;
- **Energy – Fuel**: it considers indicators related to the fossil fuels exploitation for energy use;
- **Energy – Green Energy**: it refers to indicators that measure energy production levels from RES plants;
- **Energy – Energy Storage**: it includes indicators related to the use of energy storage systems (ESS);
- **Energy – W2E**: it includes indicators that measure the adoption Waste-to-Energy (W2E) solutions, indeed energy production from waste recovery;
- **Smart Grid and Balancing:** it includes indicators that measure data related to the electric grid and the balancing of the production sources and consumption loads;
- **Energy**: it presents other energy indicators not classified in the previous subcategories.

The following subcategories describe the category Ecosystem:

- **GHG Emissions**: it considers indicators for measuring Greenhouse gases emissions such as CO_2 and CH_4;
- **Water Management**: it refers to indicators that monitor water management and usage;
- **Other Resources Usage**: it considers indicators for measuring the exploitation of resources such as soil and other raw materials;
- **Ecosystem**: it includes indicators that refer to the biodiversity of the city, monitoring the preservation of natural areas and native species

The following subcategories form the category Pollution:

- **Pollution**: it includes indicators for detecting and measuring pollutants such as O_3 and Particulate matter concentrations, as PM2,5 and PM10;

- **Pollution – Noise**: it assesses indicators for monitoring noise pollution levels in the city.

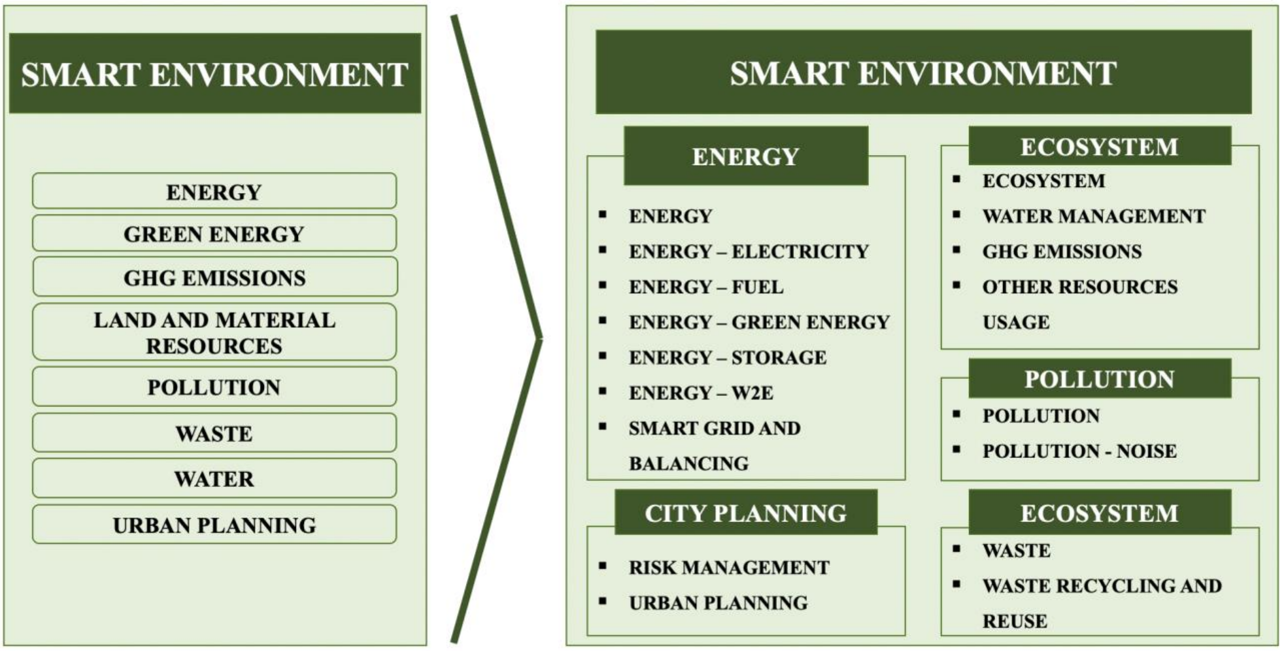
The following subcategories describe the category Waste:

- **Waste management**: it assesses indicators for monitoring waste management systems and landfills utilization;
- **Waste recycling and reuse**: it defines indicators related to circular economy practises for end-of-life products, such as material recycling and product reuse.

Finally, the following subcategories form the category City Planning:

- **Urban Planning**: it assesses indicators that detect the city planning and distribution of resources to the population;
- **Risk Management**: it refers to indicators that detect risk prevention and management measures on natural disaster as earthquakes and flooding.

The figure below resumes the structure of the smart environment pillar, showing the theoretical classification on the left and the final version on the right.



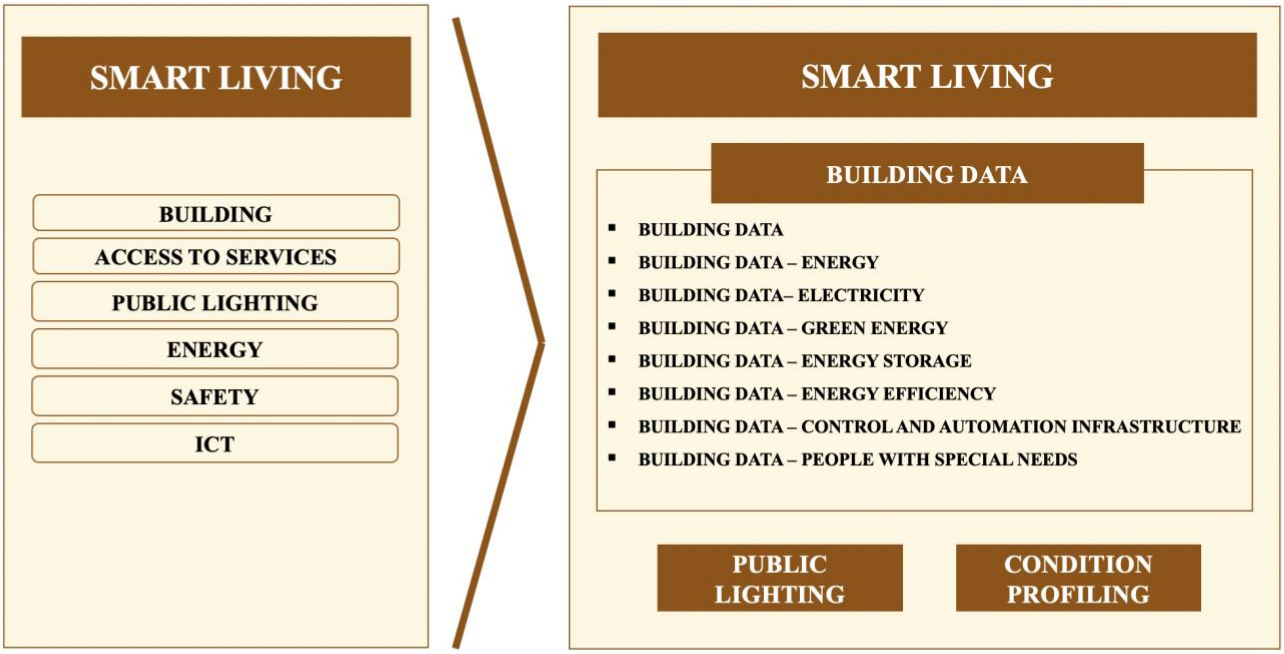
5.1.2 Smart Living

The smart living pillar, as described in section 1.2 of the work, aims at improving the urban living conditions of its citizens, through the optimization of public services and the adoption of energy efficient solutions, both of residential and public applications. The category identified for this pillar is Building Data, while the subcategories Public Lighting and Condition Profiling did not require to be grouped into categories.

The subcategories forming the category Building Data are:

- **Building Data**: it assesses indicators for general information regarding buildings in the city;
- **Building Data – Energy**: it defines indicators for monitoring energy consumption in public and residential buildings;
- **Building Data – Electricity**: it defines indicators for monitoring electricity consumption;
- **Building Data – Green Energy**: it includes indicators that assess the diffusion of residential and commercial RES plants in the city;
- **Building Data – Energy Storage**: it assesses indicators for evaluating the diffusion of Energy Storage Systems in residential, public and commercial buildings in the city;
- **Building Data – Energy Efficiency**: it includes indicators that assess energy efficiency levels in residential and public buildings of the city;
- **Building Data – Control and Automation Infrastructure**: it includes indicators that evaluate automation levels of the systems installed in public buildings;
- **Building Data – People with Special Needs**: It presents indicators that evaluate the availability of the propter infrastructure needed for people with special needs in public buildings.

The figure below resumes the structure of the smart living pillar, showing the theoretical classification on the left and the final version on the right.



SMART LIVING

- BUILDING
- ACCESS TO SERVICES
- PUBLIC LIGHTING
- ENERGY
- SAFETY
- ICT

SMART LIVING

BUILDING DATA

- BUILDING DATA
- BUILDING DATA – ENERGY
- BUILDING DATA– ELECTRICITY
- BUILDING DATA – GREEN ENERGY
- BUILDING DATA – ENERGY STORAGE
- BUILDING DATA – ENERGY EFFICIENCY
- BUILDING DATA – CONTROL AND AUTOMATION INFRASTRUCTURE
- BUILDING DATA – PEOPLE WITH SPECIAL NEEDS

PUBLIC LIGHTING

CONDITION PROFILING

5.1.3 Smart Mobility

This pillar aims at optimizing the mobility system inside city boundaries, through the diffusion of innovative and sustainable transportation solutions, such as low-emission vehicles, electric vehicles, alternative transportation, public and sharing services and smart infrastructure. The categories identified for this pillar are Infrastructure and Mobility Data. Next the different subcategories aiming at comprehensively describe the smart mobility pillar are described.

The subcategories forming the category Infrastructure are:

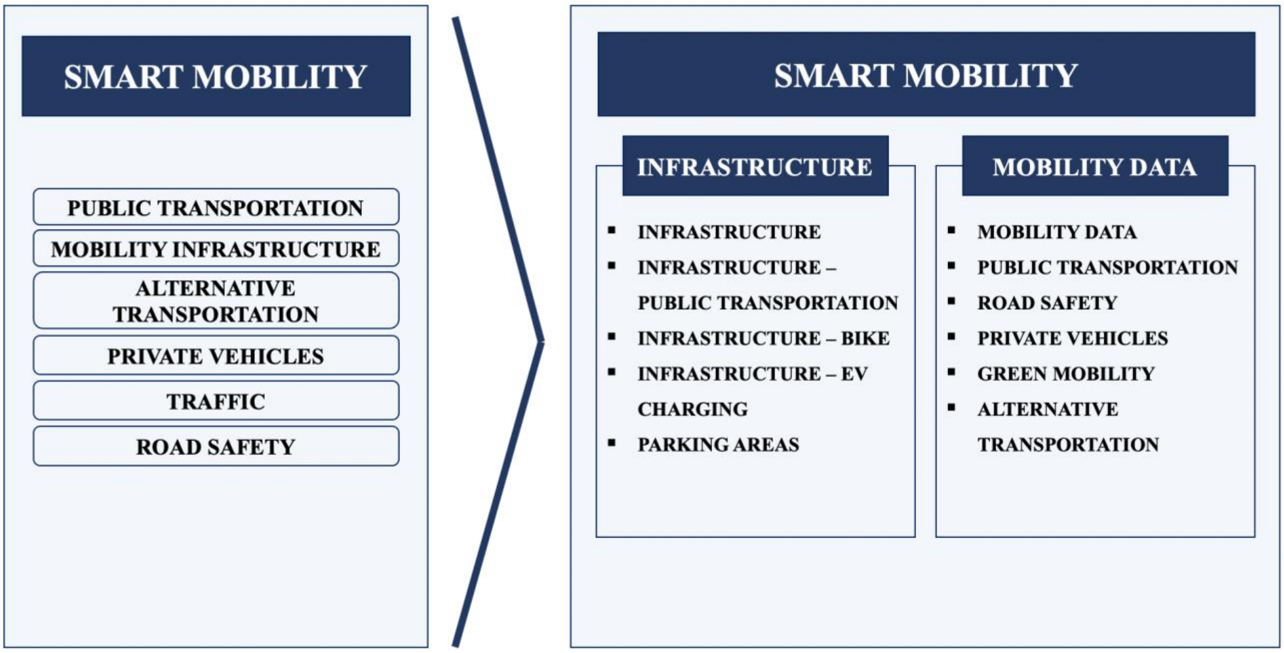
- **Infrastructure – Public transportation**: it reports indicators that evaluate the performance level of the infrastructure used in the public transportation system, in terms of availability and diffusion of the network;
- **Infrastructure – Bike**: it reports indicators that monitor the bike route network in the city and the availability of bike sharing solutions;
- **Infrastructure – EV Charging**: it includes indicators that assess the availability of public charging stations and points for electric vehicles (EV) in the city;
- **Parking areas**: it defines indicators that evaluate the availability of smart infrastructure in public parking areas, such as e-payment systems and real-time availability alert systems;
- **Infrastructure**: it presents indicators that monitor other information about infrastructure related to smart mobility, such as roads, traffic lights and pedestrian routes and crossings.

The subcategories forming the category Mobility Data are:

- **Public Transportation**: it assesses indicators regarding public transportation use and satisfaction of the citizens;
- **Road Safety**: it considers indicators that evaluate the level of traffic and congestion;
- **Private Vehicles**: it presents indicators that assess the amount of private cars and motorcycles in the city;
- **Green Mobility**: it defines indicators for evaluating the presence and diffusion of electric and low emissions vehicles such as Battery electric vehicles (BEV) and Plug-in Hybrid electric vehicles (PHEV), Fuel-Cell electric vehicles (FCEV) and Hybrid electric vehicles (HEV) in the city;

- **Alternative Transportation**: it includes indicators for evaluating alternative solutions in mobility, such as car sharing services and autonomous driving solutions.
- **Mobility Data**: it presents indicators that monitor other information about mobility, in particular regarding city traffic and viability.

The figure below resumes the structure of the smart mobility pillar, showing the theoretical classification on the left and the final version on the right.



5.2 Key Performance Indicators

The selection of indicators was based on the inventory of 54 examined indicator frameworks. In particular, after the preliminary screens described in chapter 2 and 3, according to which indicators where aggregated across the main themes identified, the overall number of indicators attributable to environment, living and mobility, which were those analyzed in-depth, was about 1470 out of 2612. The majority of the indicators presented have been derived from those just mentioned, reviewing the fully or partially defined ones and recreating those presenting insufficient information. In addition, some new indicators have been suggested to fill gaps in existing frameworks.

To arrive at the final set of indicators, a set of criteria was used, based on those recalled by the CITYkeys framework (Bosch et al. 2017).

- Relevance: each indicator should have a significant role for the evaluation process and all the indicators should have a consistent relation to the subcategories of the framework. Moreover, the indicators should be defined in a way that the possible implementation of a smart city would provide an evident change of the indicator value.
- Completeness: the set of indicators should consider all the aspects of the energy related pillars. This is why categories and subcategories have been identified, and specific indicators have to be assessed for each subcategory in order to build a comprehensive framework.
- Availability: data for the indicators should be available and easy to be collected through the different sources of data. Indicators that require, for instance, interviews of users or dwellers are not suited as the large amounts of data needed are too expensive to gather. The current selection contains, however, a few indicators that might be expected to become common in the near future (e.g., Urban ecological footprint). In case data availability for a specific indicator is difficult, it has to be specified and possible alternatives for the measurement can be evaluated (i.e., shifting the perimeter of analysis from city scale to national scale).
- Measurability: an indicator has to be easily measured in an objective way. For energy pillars, it should not be difficult to define quantitative and objective indicators.
- Reliability: the definition and the calculation method of each indicator should be clear and not open for different interpretations. This holds for the definition itself and for the calculation methods behind the indicator.
- Familiarity: each indicator should be easy to understand in by the users.
- Non-redundancy: indicators should not be overlap with each other, since they have to measure different aspects for the pillar.
- Independence: any change in an indicator should not have an impact in the evaluation (positive or negative) of other indicators of the framework.

Finally, the KPIs, that are extensively presented in Appendix XX, are defined according to the following features. i) Name of the indicator; ii) Description, in particular the full description of the characteristics and boundaries of the indicator; iii) Calculation, in particular all the information that must be taken into account for the calculation and the formula for the measurement; iv) Unit or Measure; v) Perimeter of analysis, in particular the spatial scale of the indicator measurement; vi) Frequency of reporting, in particular how frequently the indicator must be updated and reported; vii) Scoring (on a scale from 1 to 5), in particular it is the aggregated value of three dimensions: cost of collecting the data, availability of tools for collecting the data, and capability of interacting with third parties for collecting the data. Note that since those values are clearly different for different types of cities, the proposed value is general, and it has been evaluated according to the results obtained from the survey presented in chapter 4; vii) Notes, in particular additional notes regarding the nature or the evaluation of the indicator.

5.3 Overall Structure

In this section, an overall picture of the framework will be presented. This represents only skeleton of the system. In fact, as mentioned above, the key performance indicators are fully presented in Appendix XX.

Pillar	Category	Subcategory	KPI
Smart Environment	Energy	Energy	Final energy consumption per capita
			Energy intensity
			Energy used in recycling
		Energy - Electricity	Electricity production per capita
			Electricity consumption per capita
			Electricity in the energy mix
			Percentage of city population with authorized electrical services
		Energy - Fuel	Fuel energy consumption per capita
		Energy – Green Energy	Renewable energy generated within the city
			The percentage of total renewable energy sources (RES) self-supply
		Energy – Storage	RES power installed
			RES storage capacity installed
			Grid storage capacity per total city energy consumption
		Energy – W2E	Percentage of city's solid waste that is treated in energy-from-waste plants
		Smart Grid and Balancing	Average number of electrical interruptions
			Average length of electrical interruptions
			Smart meters
	City Planning	Risk Management	Population living in disaster-prone areas

			Natural disaster related deaths
			Disaster risk management in city planning
			Critical infrastructures
		Urban Planning	Brownfield redevelopment
			Green and water spaces
			Commercial and industrial activities
			Residential areas
			Transport areas
			Areas for social infrastructures
			Unused Areas
			Basic service proximity
			Population density
			Housing located in informal settlements
	Ecosystem	Ecosystem	Number of native species
			Ecosystem protected areas
			Urban ecological footprint
			Climate resilience strategy
			Urban heat island
		Water Management	Water consumption
			Population served by wastewater collection
			Water losses
			Population with potable water supply service
			Water service interruptions
			Smart water meters
			Real-time water quality tracking
		Other Resources Usage	Domestic material consumption
		GHG Emissions	CO2 emissions
	Pollution	Pollution	air quality index
			PM 2.5 concentration
			NOx concentration
			Air quality monitoring stations
		Pollution – Noise	Noise pollution
	Waste	Waste	Solid waste collection
			Municipal solid waste
			Waste drop-off centers telemetering
			Sensor-enabled public garbage bins
		Waste Recycling and Reuse	Recycling rate

			Hazardous waste recycled
Smart Living	Building Data	Building Data	Total number of residential buildings
			Total number of public buildings
			Total number of commercial buildings
			average age of the buildings
			Number of historic and artistic buildings and views
		Building Data - Energy	Thermal energy consumption of public buildings
		Building Data - Electricity	Electricity consumption of public buildings
		Building Data – Green Energy	Green "prosumer" residential buildings
			Green "prosumer" public buildings
			Green "prosumer" commercial buildings
		Building Data – Energy Storage	Residential buildings with an energy storage system
			Public buildings with an energy storage system
			Commercial buildings with an energy storage system
		Building Data – Energy Efficiency	BEMS in public buildings
			Public building sustainability certifications
			Residential buildings with "energetic class A" or higher levels
			Public buildings with "energetic class A" or higher levels
			New buildings with energetic class A or higher levels
			Buildings refurbished to higher energetic class
		Building Data – Control and Automation Infrastructure	Public buildings equipped for monitoring indoor air quality
		Building Data – People with special needs	Public buildings completely accessible by persons with special needs
			Barrier-free areas in public buildings
	Public Lighting	Public Lighting	Electricity consumption of public street lighting
			Light performance management system in public street lighting
			New installed and refurbished public lighting systems

			Number of service suspensions in public lighting
			Average duration of service suspensions in public lighting
			Maintenance costs associated with public lighting
	Condition Profiling	Condition Profiling	Durations exposure to daylight during winter
			Durations exposure to daylight during summer
			Daily average temperature registered during winter
			Daily average temperature registered during summer
Smart Mobility	Infrastructure	Infrastructure	Marked pedestrian crossings equipped with accessible pedestrian signals
			City streets covered by real-time online traffic alerts and information
			Percentage of traffic lights that are intelligent/smart
			Pedestrian infrastructure
			Road density
			Periodic maintenance of roads
		Infrastructure – Bike	Length of bike route network
			Cycle lanes availability
			Bike sharing coverage
		Infrastructure – EV Charging	Public charging stations for e-vehicles in the city area
			Public charging points for e-vehicles in the city area
		Parking Areas	Public parking spaces equipped with e-payment systems
			Public parking spaces equipped with real-time availability systems
		Infrastructure – Public Transportation	Length of public transport system
			Public transport lines equipped with a publicly accessible real-time system
			Public transport network covered by a unified payment system
			Smart proximity to public transport
	Mobility Data	Mobility Data	City commuters using a travel mode to work other than a personal vehicle
			Average commute time
			Traffic index

	Private Vehicles	Number of personal automobiles per capita
		Number of two-wheeled motorized vehicles per capita
	Green Mobility	Number of Electric vehicles (EV) registered in the city
		Percentage of vehicles registered in the city that are low-emission vehicles
	Alternative Transportation	Number of autonomous driving vehicles
		Access to car sharing solutions for city travels
		Number of users of sharing transportation per 100 000 population
	Road Safety	Traffic accidents per 100 000 population
		Transportation deaths per 100 000 population
	Public Transportation	Public transport use
		Average age of public transport fleet

5.4 Contribution to the gaps examined

The overall examination concerning the contributions, the limits and avenues for future research of this work is presented in chapter 6. This final section aims at critically evaluating to what extent the gaps identified during the whole work has been bridged.

First, the **system completeness** is considered. The proposed model is composed by X key performance indicators focused on the ‘energy’ pillars of the smart city. Thanks to the incredible amount of data and information from which the proposed performance measurement system stems from, as described above, significant improvement has been done. In fact, the advancements achieved in terms of indicators measured allow a greater level of specificity of the whole system. However, the built framework does not present indicators for the other three smart city pillars smart economy, smart governance and smart people that are fundamental objectives to be pursued in the future. Moreover, the system completeness refers also to the process of continuous improvement of such work. In fact, the indicators composing the system must be periodically updated and renewed according to the cities needs and challenges.

Then, for what concerns the indicators **subjectivity**, the issue has been addressed and all the KPIs constructed in a way that the boundaries of definition and calculation are fully objective.

Moreover, the design of indicators was carried out in a way that ensures no **overlapping** issues between two or more measures. Thus, the boundaries of definition and calculation of KPIs must not lead to the same measurement of data. However, without having a full understanding of the structure of municipalities databases, some intertwining data can happen and the real contribute to this gap can be appraised only by the real application of the framework.

Furthermore, the framework was defined in order to provide a **complete measure** of KPIs. Thus, they were constructed in a way that all the dimensions affecting their measurement are taken into account, according to its definition. However, again, since the authors did not build the indicators with the complete collaboration of municipalities, a full perception of the advancements can be evaluated only by testing the system in a real scenario.

To continue the critical analysis, the collection of data and information obtained through the involvement of the **Italian municipalities** resulted essential in understand the big picture of the country. However, the collaboration with stakeholders of different types should be total also in designing the model. Moreover, the proposed indicators have not been **tested**, which represents a great limitation.

Finally, the all the gaps identified under the category **data availability limits** as well as the **interpretation/comparability** limit are strictly dependent from the testing phase of the framework. Thus, they have not been addressed.

The table below gives an overview of the status of the gaps after the work proposed by the authors, and it can be noticed that much remains to be done. Regarding the last column, as explained above, the complete examination of the limits and avenues for future research of this work is presented in chapter 7.

Gap	**Status**	**(New) Challenge**
System Completeness	Partially addressed	Remaining pillars to be addressed, and continuously improve the framework

Stakeholders Involvement	Partially addressed	Collaboration in both KPIs creation and in testing the framework
KPIs Testing	Unaddressed	Test the framework
KPI Design Limits		
Subjectivity	Solved	–
Overlapping KPIs	Partially addressed	Verify the advancements with municipalities
Incomplete Measure	Partially addressed	Verify the advancements with municipalities
Interpretation/Comparability	Unaddressed	Test the framework
Data Availability Limits		
Difficult Data Collection	Unaddressed	Test the framework
Inaccurate or Unavailable Data	Unaddressed	Test the framework
Recall error	Unaddressed	Test the framework

In this chapter the new proposed monitoring framework is defined and explained, with the inclusion of Key Performance Indicators for each subcategory of the energy pillars. In chapter 6, the authors show a survey addressed to Italian cities in order to capture the main context-specific factors that characterize the Italian landscape, regarding difficulties in measuring and monitoring energy performances of the city. The information gathered from the survey could be a potential source of further adjustment of the proposed monitoring framework, in order to better respond to the current, in order to better respond to the current priorities and challenges of Italian cities.

6 SURVEY OF ITALIAN CITIES

The sixth chapter is fully dedicated to a survey the authors have conducted on the main issues and limitations in the application of Smart City KPI monitoring frameworks in the Italian context.
From the literature review carried out in chapter 2, it emerges that in many cases there are some context-specific factors that have to be taken into consideration during the development of KPI monitoring frameworks for Smart Cities, as they limit the range of application of the framework (section 2.3). With the survey the authors try to investigate on the main priorities, challenges and issues for Italian cities in measuring and monitoring their performances, in order to define the context-specific factors of the Italian landscape.
Indeed, since the presence of context-specific factors influences the application and validity of the framework in a specific geographical region, the aim of chapter 6 is to define the main issues and limitations in the application of KPI monitoring frameworks for the energy pillars of Smart City in the Italian context, considering as targeted audience the main actors involved in the development, implementation and monitoring of the Smart City energy solutions in Italian cities and towns in year 2020. Once identified the main difficulties for the Italian context, the authors' proposed framework can be effectively tested Italian cities. However, the testing phase of the framework in Italian cities has not be done by the authors of the work yet, and can be considered as an avenue for future research.

The chapter begins illustrating the object of research, the targeted audience of the survey and the survey structure. A clear description of the methodology followed in the development and application of the survey is reported, explaining how the recipients of the survey have been selected and contacted. In addition, the questions that have been addressed to the recipients are also showed, with a reference to the specific literature gap that is object of the analysis.

Then, a precise analysis of the results of the survey is carried out, starting from each specific question and the considerations that emerge from the related answers. Cities are divided in 3 categories according to their size (e.g. number of inhabitants), since they may have different issues in the monitoring of Smart City energy aspects.

Finally, the overall marks that the survey arises are reported and discussed, highlighting the main difficulties for Italian cities in measuring and monitoring Smart City performances.

6.1 Objectives, targeted audience and structure of the survey

6.1.1 Object of the survey

The survey has been developed by the authors of this work, in collaboration with the Energy&Strategy Group of Politecnico di Milano. It is composed of different sections, corresponding to the different issues that are today hampering the diffusion and implementation of KPI monitoring frameworks for Smart Cities in the energy pillars, therefore in Smart Environment, Smart Living and Smart Mobility.

The main goal of the survey is to assess which are the main issues in the application of KPI monitoring frameworks for Italian Cities, according to the actors that in 2020 have been responsible of one or more aspects related to the energy pillars of the Smart City. The survey enables the authors to identify the context-specific factors of the Italian landscape that influence the applicability and validation of the proposed monitoring framework, as reported in chapter 2.3 regarding the existing difficulties in extending the geographical range of application of a framework. After the identification of the main peculiarities of the Italian context, the framework can be effectively tested and implemented by Italian cities, and the actual implementation of the framework in Italian context can be considered as an avenue for future research.

The main objects of evaluation are the current gaps of literature regarding monitoring frameworks as KPI design, data availability and stakeholder involvement, that have been found the literature and assessed in chapter 2.3.

In particular for **KPI design** the issues investigated regard mainly applicability of the measure, data interpretation and KPI conditions, while for **data collection and availability** the main limits object of the survey are difficult data collection and inaccurate or unavailable data. Furthermore, for the gap of **stakeholder involvement** it is investigated in which way the city deals with external data owners, such as public or private companies and statistics entities.

For each of the identified limits, the aim is to assess how much the issue is relevant and in which specific Smart City energy pillars and subcategory it mainly occurs, according to the different experiences of the Italian cities that took part to the survey.

6.1.2 Targeted Audience

The targeted audience of the survey are the actors responsible of the Smart City projects in Italian Cities, especially for the energy aspects, therefore environment, living and mobility.

The authors considered cities of different sizes and belonging to all geographical areas in Italy, starting from the metropolitan cities and the capital of each Italian province, to arriving to each single town and municipality.

Different ways have been followed for the diffusion of the survey, dividing all the municipalities in Italy in 2 categories:

- Category 1: metropolitan cities and the capital of each Italian province (107 cities);
- Category 2: all the remaining cities, towns and municipalities in Italy.

For cities belonging to category 1 the authors looked for the direct contacts of the actors responsible of implementing Smart City projects and measuring the performances. It has been possible to identify the persons currently in charge of these responsibilities and their related contacts looking on the municipal website of each of the selected 107 cities.

In particular, for actors responsible of Smart City energy aspects, different roles have considered inside the city, which belong to two different streams:

- **Members of the Municipality** with a delegation on Smart City themes or on energy aspects of the city, in particular figures such as city mayors, executives, secretary-generals and assessors to mobility and/or environment, environmental sustainability, infrastructure, waste, energy, urban planning, urban health, public green areas, innovation, digital transformation;
- **Heads of city departments** responsible of Smart City development or of energy aspects of the city, in particular figures such as general directors, secretary-generals, heads and managers responsible of Smart City and/or urban planning, environment, environmental sustainability, ecology, mobility, public lighting, infrastructures, waste, energy, digital transformation, public affairs.

There have been collected from 2 to 5 contacts for each of the 107 metropolitan cities or capitals of each Italian province, in order to cover the majority of the Smart City energy aspects and have more probability of receiving a feedback.

These figures have been contacted personally through e-mail. In total, 319 different persons were contacted, firstly in August 2020 and then again in October 2020 for the ones that did not replied the first time. In the end, 58 out of these 319 contacts replied to the survey, corresponding to 20 out of the 107 cities contacted. 15 of the recipient cities belong to the North part of Italy, 2 cities are in Central part of Italy and 3 cities are present in the South.

For the remaining Italian cities, towns and municipalities, that belong to category 2, it was unfeasible to identify each person responsible of one or more energy aspects of Smart Cities. Therefore, the authors used a free-public access database containing 1 reference e-mail for each Italian single municipality, in particular the related certified electronic mail (PEC). The database can be found on the website page of the portal “Italia in dettaglio”, in section “e-mail e PEC dei comuni italiani” (Reti e sistemi 2019).

After having found the database on the website, the following Visual Basic function has been used in order to obtain the data on Microsoft Excel:

```
Public Function Estrai_Indirizzi (ByVal Collegamento As Excel.Range)
Estrai_Indirizzi = Replace(Collegamento.Hyperlinks(1).Address, “mailto:”, “”)
End Function
```

The survey was sent to these PEC mails in September 2020. As the contacts were just reference mails and they were not addressed to a specific person responsible of Smart City aspects, just 28 answers out of 7890 contacts of the database have been received. Moreover, it is clear that the majority of small size towns may not implement Smart City projects and/or keep track of related performances. However, these further answers undoubtedly enriched the survey, since in this way the sample is very various, with a mixture of big and small-size Italian cities and municipalities.

Th authors decided to address the survey only to Italian cities and towns because the aim is to assess the context-specific factors that especially characterize the Italian landscape. Moreover, since all the targeted audience is composed by Italian speakers, the survey is written in Italian language.

In the end, the authors managed to contact and receive feedbacks from 32 cities and municipalities which totally account for 4.9 Million of inhabitants, corresponding to the 8% of total Population in Italy. For this reason, the results of the survey can be considered robust and reliable, therefore a relevant source of information for additional analysis.

6.1.3 Survey Structure

The survey is composed by **8 Sections**, in which there is one or more questions depending on the previous answers. The sections are referred to current gaps and limits of monitoring frameworks that arise in KPI design, data collection and availability and stakeholder involvement, which have been found and reported in chapter 2.3.

In particular, for each section it is assessed whether the identified gap is effectively a recurrent issue for the city in the implementation of the monitoring framework, in which Smart City pillars and subcategory of the proposed framework the issue is mostly relevant, and the main reasons of the reported difficulty.

In **section 1** it is assessed whether there is difficulty in data collection for KPI implementation, in which specific subcategories it is the most complex to collect robust data and whether this difficulty is determined by the absence of reliable tools and devices for data collection and measurement.

For a precise and rigorous data collection it is fundamental to have available accurate infrastructure, that can properly store historical values and analyze the variations in different time series. The expectation is that not all the Italian cites can benefit from a reliable data collection system.

This section is referred to the current literature gap of **data collection and availability**, which emerge both in chapter 2.3. In particular the section investigates on the issues of difficult data collection and inaccurate or unavailable data.

In **section 2** there is again a reference to the difficulty in data collection of KPI implementation. It is wondered if the problems related to data collection are caused by the expensiveness of the data collection system. Actually, the authors imagine that not all the cities can stand the demand needed to punctually measure and keep track of the performance of the city, in terms of money, time and resources allocated. In the section it is also investigated in which specific energy pillars and subcategory the issue is mostly relevant.

This section is linked with the current literature gap of **data collection and availability**, regarding the issues of difficult data collection and inaccurate or unavailable data.

Section 3 assesses whether there is a difficulty in the interaction with third-party entities which are the owners of the data the city needs to measure the indicators. Third parties are mainly transmission system operators (TSO), distributor system operators (DSO), other private or public companies, public entities, statistics entities and citizens, therefore stakeholders that the members of the

Municipality and the heads of city departments have to deal with in order to obtain useful data for the measurement of the KPIs.

The expectation is that it is not always easy to interact with the data owners, since they might be not interested in divulgating the data. In the section it is investigated also the main reasons at the basis of this issue.

This section refers to the limitations regarding the gap of literature **stakeholder involvement**, a theme described in chapter 2.3.

In **section 4** it is wondered if the way in which the data is collected is coherent or not with the KPI conditions and specifications. In order to become useful information, data has to be precise, punctual and well-determined. Only the expressed data is required for the KPI calculation, and it has to refer to the right time period and space which is object of analysis. This is fundamental in order to guarantee standardization of the KPI framework, avoid problems of measure interpretation and facilitate comparability with past years or with different cities.

This is connected to 3 existing issues that emerge from the review and analysis presented in previous chapters. For sure, it is connected with the limitations in **data collection and availability**, since inaccurate and not coherent data are a common problem evidenced in data collection and availability. It also involves the limitations in **KPI design**, in case the data collected is incoherent with the timeframe required by the indicator conditions and specifications. Furthermore, an inconsistent implementation of the indicator hampers its correct interpretation and comparability with other cities.

In **section 5** it is investigated whether cities exclusively use internal sources of data for the computation of the indicator, in order to overcome issues related to stakeholders involvement. It is also assessed for which specific energy measures the exclusive use of internal sources of data is the most recurrent.

This section refers to the existing limits in **data collection and availability**, in particular the difficult data collection, and with the difficulties in **stakeholders involvement**.

Section 6 evaluates which measurement systems are mainly adopted by cities for data collection, in case data collection is done through internal sources. In particular, there are two possible types of solutions that cities can adopt:

- The use of simple measurement devices, such as sensors;
- The implementation of a real monitoring system, mainly through software applications.

This is again connected to the existing limits in **data collection and availability,** referring to the difficulties in data collection, as described in chapter 2.3.

Section 7 is instead focused on the utilization of external data sources for data collection and the implementation of the indicator. It is assessed which are the actors that cities have to interface in order to get the required data. The expectations are that in many cases the use of external data sources is necessary, otherwise the indicator results very complex and onerous to calculate.
This section referred to the existing issues in **stakeholder involvement**.

Finally, **section 8** investigates on the main criticalities related to the development and implementation of a framework of indicators for Smart Cities. It is assessed whether there are problems in defining the correct formula of one or more indicators and whether there are issues of interpretation of the measure in an objective way. It is also questioned whether there are issues in the comparability of the indicators among different cities.
This section is related to the issues in **KPI design**, in particular with limits such as applicability of the measure and data interpretation.

The table below summarizes the different parts that compose the survey and which limits described in chapter 2.3 each section refers to.

Section	Question	Gap investigated
1	Absence of reliable tools and devices for data collection	Data collection and availability
2	Expensiveness of the data collection system	Data collection and availability
3	Difficulty in the interaction with third parties	Stakeholder involvement
4	Incoherency between data collected and KPI conditions	KPI design, Data collection and availability,
5	Exclusive use of internal sources of data	Data collection and availability, Stakeholder involvement
6	Adoption of internal measurement systems	Data collection and availability
7	Inclusion of external sources of data	Stakeholder involvement
8	Difficulty in KPI structure and use	KPI design

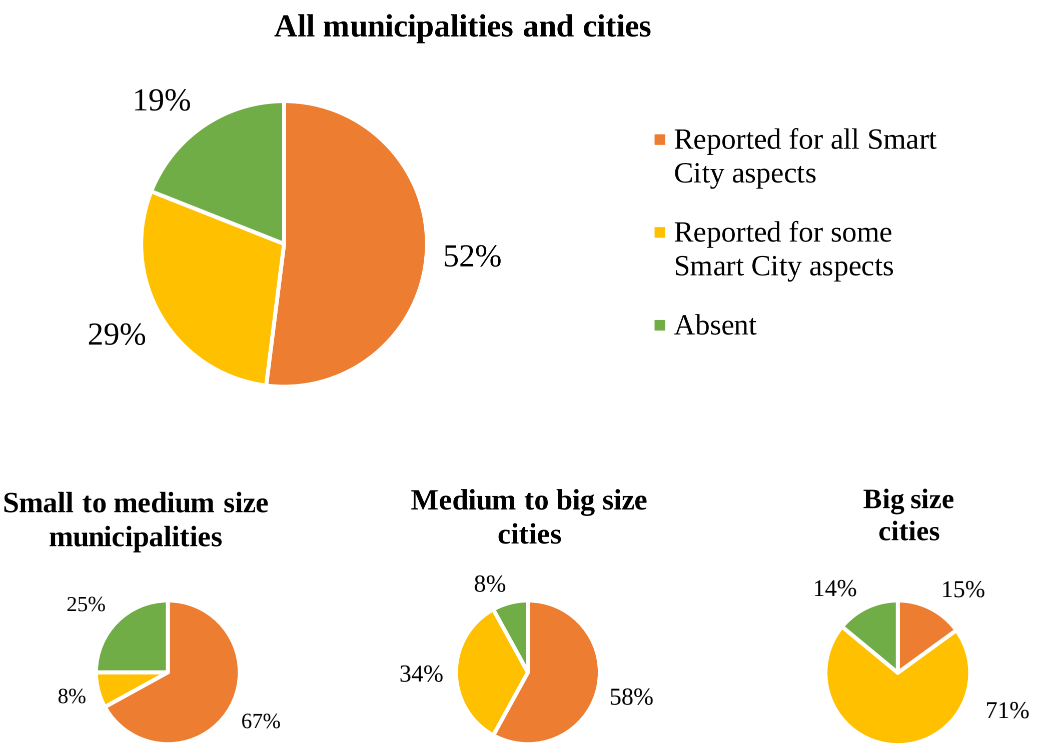
6.2 Analysis of the Results

In this section the results of the survey are reported and analyzed, considering each part separately. For each part, it is reported not only the overall feedback received, which considers all the answers received from all the different cities and municipalities that took part to the survey, but also the different results considering 3 different groups of municipalities and cities, divided by the size (e.g. number of inhabitants):

- Group 1: small to medium size municipalities: this includes all the municipalities that have contributed to the survey and that have less than 50 000 inhabitants;
- Group 2: medium to big size cities: this includes all the towns and cities that have contributed to the survey and that have between 50 000 and 250 000 inhabitants;
- Group 3: big size cities: this includes all the cities that have contributed to the survey and that have more than 250 000 inhabitants.

For some of the issues object of investigation, in the related section it is reported also the subcategories of the authors' proposed framework in which the issue is particularly evident, according to the recipients. In this way it is possible to punctually adjust the indicators of the proposed framework that belong to a subcategory, on the basis of the issues reported by the survey regarding that subcategory and effectively test the framework in the Italian context in real cases.

Section 1: Absence of reliable tools and devices for data collection


All municipalities and cities

Small to medium size municipalities

Medium to big size cities

Big size cities

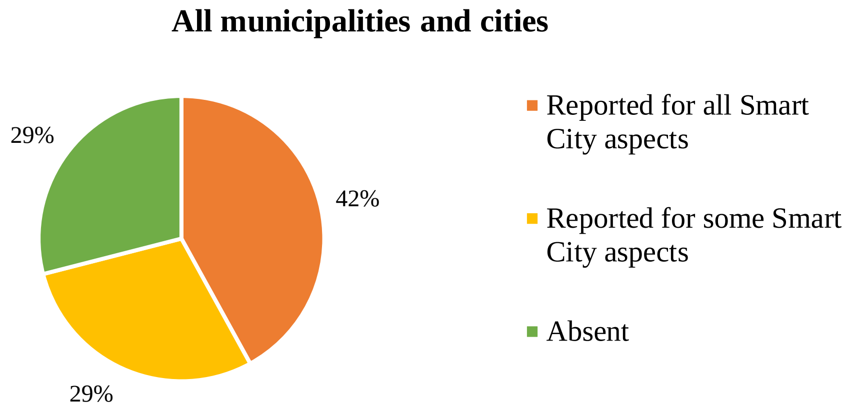
Considering all the sample analyzed, for more than 80% of the municipalities and cities there is a difficulty in data collection, caused by the unavailability of reliable and consistent tools and devices for data measuring and collection.

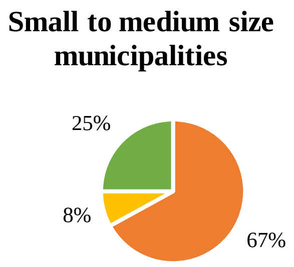
This issue is particularly evident in small to medium municipalities, while it is less impactful in bigger urban centers. This is because big size cities may have more resources involved and dedicated to Smart City monitoring frameworks and can usually benefit from the latest technologies available, which indeed offer the most efficient services.

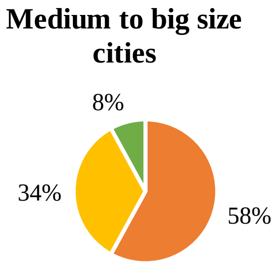
This criticality is reported for all Smart City aspects in more than the 50% of the municipalities and cities interviewed.

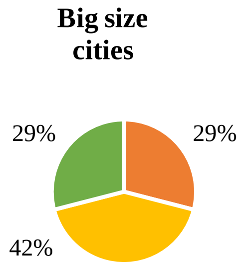
In some cities the issue is not reported for all Smart City aspects but just to some of them. In particular, this problem is particularly redundant for indicators referring to subcategories Energy and Energy efficiency of Smart Environment and to subcategory Mobility Data – Public transportation of Smart Mobility.

Section 2: Expensiveness of the data collection system









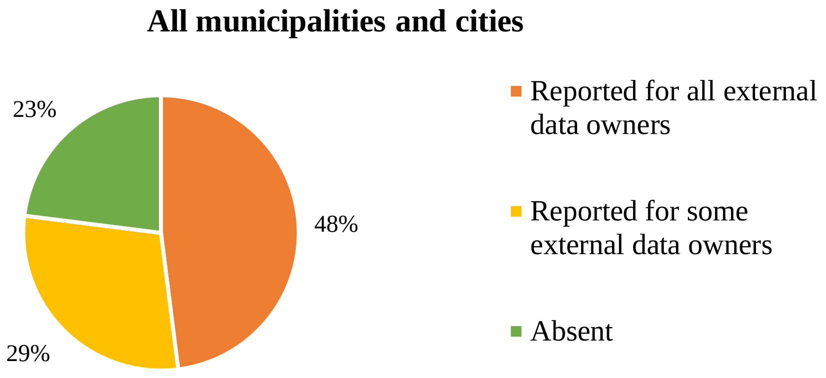
More than 70% of the sample analyzed reports that the data collection system is too expensive in terms of money and resources to allocate, causing difficulties in data collection and measurement of defined indicators.

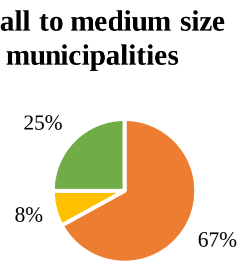
In line with part 1, this issue is particularly redundant in small to medium municipalities, while it is less evident in bigger cities. This is because big size cities can undoubtedly invest more money and resources to Smart City monitoring systems, while small town may have limited budget available and dedicated for data collection systems.

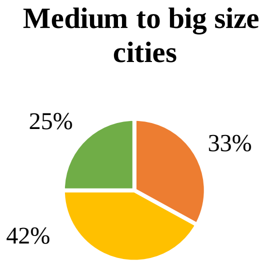
This criticality is reported for all Smart City aspects in almost half of the municipalities and cities interviewed.

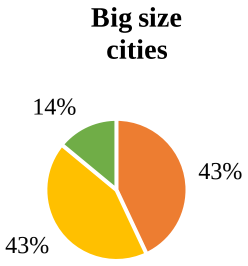
In some cities the issue is not reported for all Smart City aspects but just to some of them. In particular, this problem is particularly recurrent for indicators referring to the subcategory Energy-Electricity of Smart Environment and for indicators that refer to subcategories Mobility data and Mobility data-Public transportation of Smart Mobility.

Section 3: Difficulty in the interaction with third parties


All municipalities and cities


Small to medium size municipalities


Medium to big size cities


Big size cities

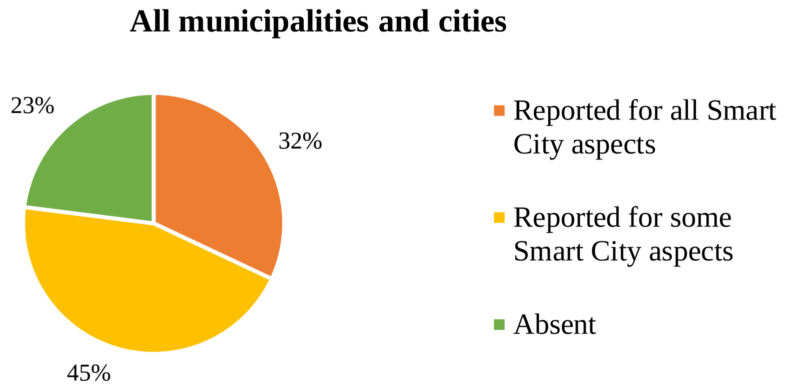
From part 3 of the survey, it emerges that in the 77% (48% + 29%) of the cases there are issues in the interaction with third parties that are external data owners, as transmission or distributor system operators (TSO or DSO), private or public companies and statistics entities.

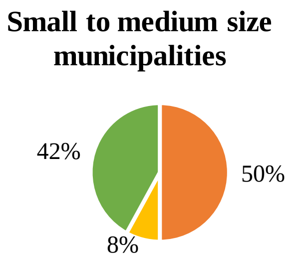
In general, there is low interest of private companies in collaborating with public entities, due to different objectives and priorities. In fact, private companies may consider this collaboration a no-value-added activity, as it required dedicated time and resources and brings low or no economic return.

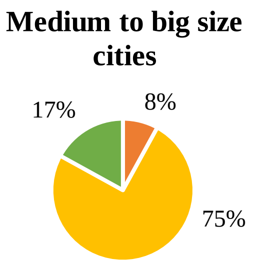
The main challenging themes are the concept of data ownership and the lack of a national or regional legislation that can provide the necessary support for data management and exchange. Moreover, the cost of the infrastructure needed for a periodic or real-time exchange of data between the municipality and third parties is an additional hurdle to this collaboration.

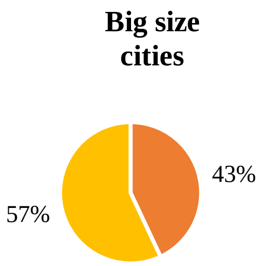
This issue is less predominant the bigger the municipality is, probably because external data owners are more willing to cooperate with big size cities, in order to get more return in terms of visibility and image. For instance, having cooperated with a metropolitan city for the measurement of energy consumption may be a major source of advertising for the private company, compared to cooperate with a small municipality.

Section 4: Incoherency between data collected and KPI conditions





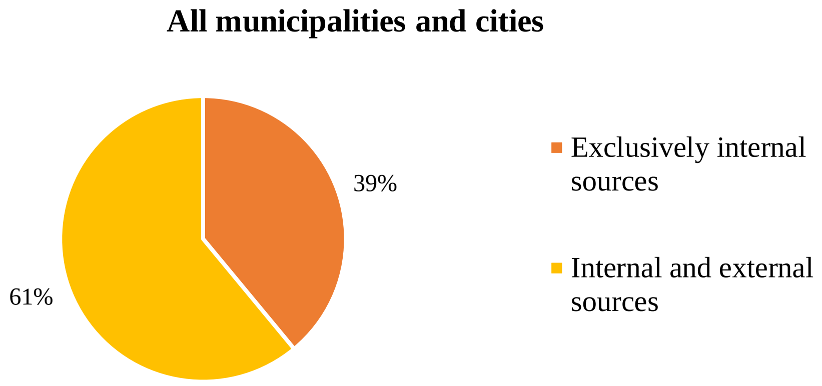


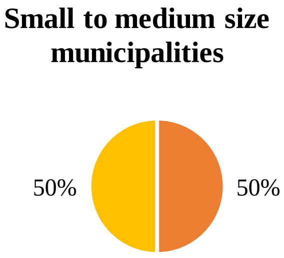


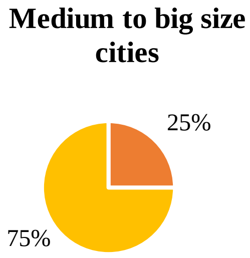
The way in which data is collected is not coherent with the indicator conditions and requirements in more than 75% of the sample analyzed, and it is particularly relevant for big cities.
Of course, at the basis of this issue there can be different limitations, which range from a weak data collection system, in which data collected are not the ones that are required, or it may occur due to limitations in KPI design, if the measure is not clearly defined and leads to subjective interpretations, that hamper comparability among cities. It may be also a problem of time relevance, if data collected are not referring to the same time frame the indicator aims to measure and there is not a standardized frequency of reporting of the indicator.

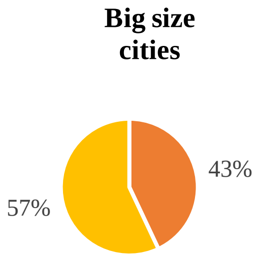
This problem is particularly recurrent in indicators of Smart Environment referring to subcategories Energy- Electricity, Ecosystem-GHG Emissions and Pollution, and for Smart Living indicators that refers to subcategory Building data- Electricity.

Section 5: Exclusive use of internal sources of data


All municipalities and cities


Small to medium size municipalities


Medium to big size cities


Big size cities

Almost 40% of the municipalities and cities that took part to the survey use only internal sources of data for the calculation of the indicators.

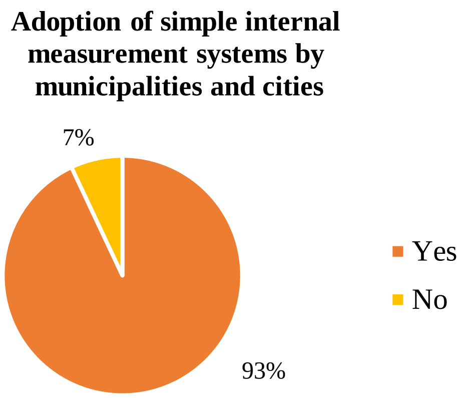
This percentage is really higher than the authors' expectations, considering that data owners are often third parties external to the members of the municipality and the city department, therefore interaction with them is often necessary and/or the quickest way to obtain the needed measure.

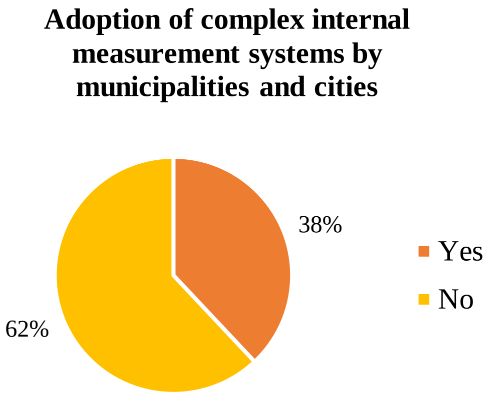
The main threat is that cities that only use internal sources of data for monitoring Smart City performances may not have a comprehensive view of all the aspects related to Smart Cities, since they may not have all the data required for a broader and more complete perspective.

According to the survey there is not a common trend for which this situation is more common, if compared to the number of inhabitants of the city or municipality.

The Smart City areas related to energy measures in which this situation is more recurrent are the subcategories Energy, Green Energy and Urban Planning for Smart Environment, subcategories Building data - Energy and Building Data- Control and Automation Infrastructure for Smart Living and subcategory Mobility Data for Smart Mobility.

Section 6: Adoption of internal measurement systems





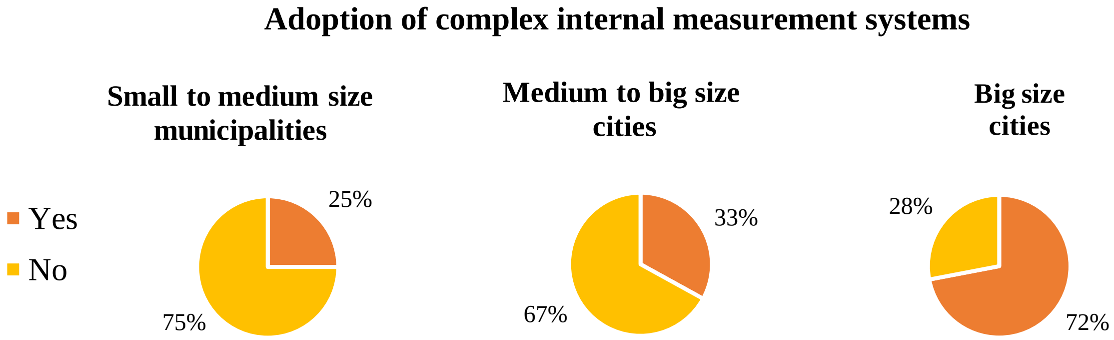
Due to the issues related with the interaction with external data owners, municipalities and cities have activated iniativies and procedures for the direct collection of data needed for the indicators measurement.

From the survey it emerges that almost every city and municipality (93% of the answers) has adopted simple internal measurement systems, which aim just at the data collection and not to the actual implementation of a monitoring systems. The use of simple internal measurement systems is very spread, regardless of the size of the municipality or city.

The most common measurement systems for the data collection are sensors (up to 52% of the cities adopting) and manual control devices (14% of the city adopting).

In addition to or instead of simple internal measurement systems, the 38% of the cities and municipalities have adopted complex internal measurement systems, since they have installed monitoring platform for data collection, storage and reporting, mainly through appropriate software and infrastructure that permit on-time data monitoring.

The implementation of complex internal monitoring systems is more spread in big size cities.



Section 7: Inclusion of external sources of data

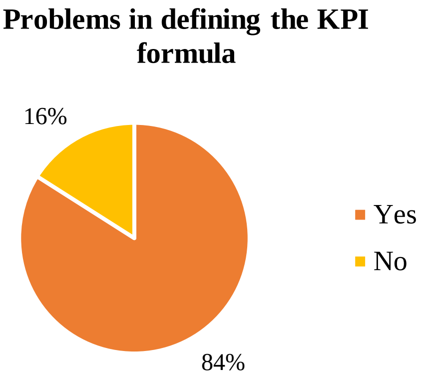
From the survey it is reported that the 61% of the cities and municipalities currently use external sources of data for the calculation of Smart City performance indicators.

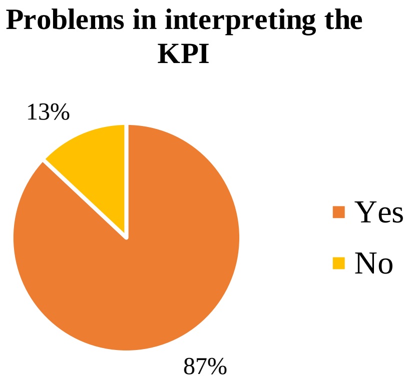
According to the results, the number of third parties that provide useful data related regarding Smart Environment, Smart Living and Smart Mobility to the municipality and city departments is very various. Data owners can be divided in the three following categories:

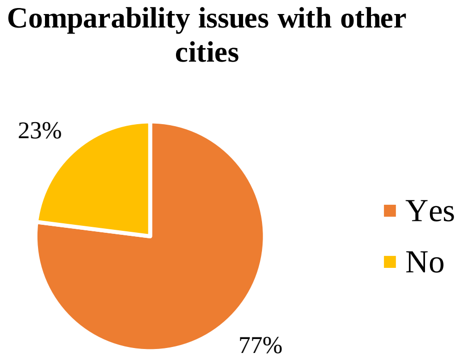
- **Public companies**, among which there are mainly reported municipal utilities, water management companies, waste management utilities, sanitary entities, public transport companies and subsidiary companies;
- **Private companies**, such as utilities or energy providers, private research centers and private entities;
- **Public and/or statistics entities**, such as regions and provinces, national Ministries, public universities and research centers, GSE ("Gestore dei Servizi Energetici"), national databases, firms' databases and ISTAT ("Istituto Nazionale di Statistica").

From the survey it emerges that small and medium municipalities have frequent difficulties in the interaction with third parties that are data owners, while these issues is less relevant in bigger cites.
In particular, the main hurdles are reported in the interaction with private companies, and this criticality is regardless of the size of the city. Instead, public and/or statistics entities such as universities, research centers and ISTAT are usually more willing to collaborate, even though universities and research centers are often not the real owners of the data and may need additional data and information from national or regional databases, utilities and public entities.

Section 8: Difficulty in KPI structure and use







From the survey it emerges that all these issues related to KPI design are widely spread in the Italian context.

In particular, the 84% of the answers reported to have problems in defining the correct formula for the indicator, which is related to the issues of KPI definition and applicability.

The 87% of the answers have encountered problems in the correct development of the indicators, in order the measure to be easily understandable and objective. This value certifies the problems of subjectivity of the indicators, which should be defined in a standardized manner.

Finally, the 77% reported problems during the implantation and usage phase, in particular in comparing measures and results with other cities. This value assesses the limitations in comparability of the indicators among cities which differ per size, geographical areas and/or different priorities.

There is not a common trend between size of the municipality and the diffusion of these issues.

6.3 Overall considerations

The survey reports diffused interest from Italian cities and municipalities in implementing monitoring systems for Smart Environment, Smart Living and Smart mobility.
However, the high level of interest is not supported by an adequate level of implemented monitoring systems and reference frameworks.

Cities and municipalities find relevant issues in the collection of data need for the implementation and calculation of the Key Performance Indicators for Smart Cities in energy aspects.
The limitations related to data availability and collection are mainly related to:

- Absence of reliable tools and devices for data collection, often due to outstanding costs associated for their procurement and implementation; Undoubtedly, medium and big size cities have more sophisticated and efficient monitoring systems compared to small municipalities.
- Recurrent difficulties in the interaction with third parties, which are the owners of the data needed for KPI implementation and calculation and that are rarely willing to collaborate with municipalities and city departments. In particular, this issue is more evident in small municipalities.

Another issue reported is the lack of a national or regional legislation, that shall provide guidelines for the process of mapping, elaboration and management of data and related measures. This current absence hampers data collection and the subsequent development of a framework of indicators. In addition, the survey certifies a lack of standardization in the definition and implementation of indicators, due to the absence of a univocal reference framework for monitoring energy aspects in Smart Cities. This issue is at the basis of inconsistent data collected, problems in defining KPI formula, subjective measures and impossibility in comparing indicators among different municipalities and cities.

With this consistent analysis, the authors identify the main issues for Italian cities in the implementation of monitoring frameworks for energy pillars of the Smart City. These considerations are very useful for actually test the framework in real cases in Italian cities, considering the context-specific factors that emerge from the analysis, in order to properly validate the framework. However, the practical testing phase has not been done by the authors yet, and can be considered as a possible avenue of further research.

7 CONCLUSIONS

This chapter marks the end of a long and incredible journey through the open water of smart cities performance measurement systems. Let’s now recapitulate the main phases of such voyage. First, it should be recalled that the authors portrayed the incredibly vast concept of smart city, describing its facets, the main challenges of a city and the importance of a performance measurement system. Intrigued by such themes, particularly by the latter, the authors deep dived into smart cities literature. The result of such diving experience gave birth to **chapter 2**, where the features characterizing a performance measurement system are extensively explained. From the review the existing literature gaps emerge, from which in **chapter 3** the authors develop the research questions of their work and build up a first theoretical framework for monitoring energy performances of smart cities. The framework is then tested and validated in the **fourth chapter** through a deep dive into the main empirical international projects of the topic, which shed light on additional peculiarities and lesson learnt from extent performance measurement systems. The inclusion of this empirical analysis enables the authors to revise and enrich their proposed performance measurement system, whose logic and value are expounded in **chapter 5**. The inherited learning allowed the authors to properly set up and conduct a survey in order to comprehend the peculiar traits of the Italian big picture, examining the problems perceived by Italian cities, illustrated in **chapter 6**. Before officially sealing the work, it is important to evaluate the overall contribution that the built smart city framework brings to methodology and practice. The other side of the picture must be discussed too, consisting in the limitations and lacunae of the work. Finally, the avenues for future research originated from limitations and opportunities of development are also indicated.

7.1 Methodological Contribution

The research design carried out in this work makes three interwoven methodological contributions to the academic literature related to smart cities performance measurement systems.

First, the set of collected primary data and information is broader and more detailed than those used in previous studies. In particular, as mentioned in chapter 5, since the authors not only reviewed the literature contributions, but also analyzed empirical projects and reports, the database created through the entire work accounts for **54** schemes that were, in turn, assessed, for a total number of key performance indicators equal to **2612**. This provided a vast understanding of the whole structure and peculiarities characterizing smart cities frameworks.

Second, this work present novel approach in investigating the performances that must be measured within a smart city. In fact, data were scrutinized at multiple levels of analysis offering the opportunity for deeper insights. Thus, the presented model stems from the joint analysis of two different types of systems. On one hand, those focused on specific aspects and areas of a city and providing very specific information. On the other, those aiming at addressing the whole picture of a city.

Third, the collection of data and information obtained through the involvement of the Italian municipalities results potentially precious, as described in chapter 6. In fact, the feedback received from local decision makers is fundamental for furtherly adjusting the proposed model, in order to shed light to possible context-specific factors and features, and create a loop of continuous improvement.

7.2 Performance Measurement System Contribution

After having delineated the methodological contributions brought during the whole project, it is important to outline also the contributions made by the built performance measurement system to its real applications, with respect to the existing issues identified through the whole project, in particular in chapters 2 and 4. In this regard, the main contributions of this work are the following.

First, the authors' model is composed by X key performance indicators focused on the 'energy' pillars of the smart city. Thanks to the incredible amount of data and information from which the proposed performance measurement system stems from, as described above, significant improvement has been done in terms of **system completeness.** In fact, the advancements achieved in terms of indicators measured allow a greater level of specificity of the whole system, with two main resulting benefits. The first is related to the city awareness of the detailed measures to be reported and monitored. The second is the intrinsic effect of accelerating the process of creating a system which is as comprehensive as possible.

Second, according to the process of designing the KPIs defined in chapter 5, the indicators were created in order to face another limit present in the existing frameworks, which is the **subjectivity** issue. Thus, KPIs were classified and constructed in a way that the boundaries of definition and calculation are fully objective. However, there are few exceptions/The only exception (VEDIAMO ALLA FINE) is represented by the XXX indicator which is measured according to a Likert scale that is not fully objective.

Third, the design of indicators was carried out in a way that ensures no **overlapping** issues between two or more measures. Thus, the boundaries of definition and calculation of KPIs must not lead to the same measurement of data. However, without having a full understanding of the structure of municipalities databases, some intertwining data can happen and the real contribute to this gap can be appraised only by the real application of the framework.

Finally, the framework was defined in order to provide a **complete measure** of KPIs. Thus, they were constructed in a way that all the dimensions affecting their measurement are taken into account, according to its definition. However, again, since the authors did not build the indicators with the complete collaboration of municipalities, a full perception of the advancements can be evaluated only by testing the system in a real scenario.

7.3 Recommendations for Practice

In this section, the authors explain the recommendations that practitioners may follow in approaching the proposed framework, and the ultimate value that they may capture from it. Please note that the term “practitioners” refers to Italian and European municipalities with different characteristics (e.g., geographical area, demography) with a more or less developed smart city strategy.

It must be understood that this framework doesn’t aim or pretend to be a complete and ultimate solution. This is not only because this work is not fully exhaustive and presents limitations, as it will be extensively described in the next two chapters, but also because as experienced in human and urban history, the concept of city is destined to evolve and will always present new challenges to be faced by civilizations. That is why, such work, wants to be the starting or mid stage of a process of continuous improvement aimed at fostering and accelerating the transition towards smart cities.

Furthermore, the built performance measurement system potentially finds a useful application in any university, regardless of whether it already adopts a measurement system or not. However, these two different “statuses” will affect the occurring scenarios for a city. Let’s take into account a municipality that is weighting up the benefits and implications of adopting the proposed system on its overall business. To apply the framework, the city must ask itself questions on how to effectively do that. The main questions that are triggered by the framework are indicated next.

- **Value proposition:** what is the value that a city gets from the proposed system? Is this consistent with the strategy pursued? (i.e., is it consistent with my entry strategy for the adoption of a performance measurement system? or is it consistent with the already adopted system?) To which extent will it affect the city?
- **Infrastructure and involved parties:** what are the key resources and competences to set up the framework? To which extent is the city equipped? If resources and/or competences lack, does the university opt for in-house development, acquisition, or outsourcing? Based on the strategy, what are the activities the city plans to execute internally, and what the ones executed externally? What are the criteria and weights applied in the selection of third parties?
- **Economic perspective:** based on the strategy, are there opportunities for some revenue streams? Can such revenues be somehow appraised? What are the major costs in applying the measurement system? How such costs will be financed? Can costs be partially or totally funded with incentives or grants? How long will it take on average to recover the investments for a measurement system?
- **Share of best practices:** what are the opportunities and benefits in spreading the adoption of the system? What are the advantages of sharing best practices among cities? What are the needed initiatives to create a communication and collaboration network?

Once those questions are answered, the city is able to evaluate its alternatives and make a decision. It must be noted that some parameters, such as the national peculiarities, the geographical area and the size, inevitably influence the strategy of cities. Therefore, to assess the feasibility and the chances of success of the proposed measurement system, some background parameters should also be considered.

7.4 Limitations

While the contributions have already been made clear, it is equally important to be transparent about the limitations of the work. The goal of this section is to present them, while the thorough picture is captured by even going through the next section of avenues for future research.

The first limitation is related to the boundaries of the performance measurement system. In fact, the proposed framework is focused on the energy pillars of the smart city, therefore Smart Environment, Smart Living and Smart Mobility. The implication of such peculiarity is that the model cannot be applied to all the areas of the city, but for now it must be narrowed to the areas of interest.

The second limitation is related to the relatively small number (i.e., 32) of cities that participated in the survey. As described in chapter 4, these cities account for approximately 4.9 million people, about the 8% of the country population. Despite the relevant amount of data gathered, this limitation does not allow to have a complete angle on the Italian picture.

Finally, the great limitation of the work regards the testing phase of the model. In fact, since the proposed performance measurement system has not been tested in a real scenario, it might lack a complete validation, which means that its actual usefulness must be still endorsed by practitioners. However, the authors believe that, based on how the whole work has been structured and carried out, the proposed framework provides a valuable strategic tool for practitioners, who can especially appreciate its clarity, profundity, and applicability. Furthermore, the development of the survey enables to test and validate the proposed framework in Italian cities, considering the context-specific factors assessed.

7.5 Avenues for Future Research

In the final section, the authors look ahead to the future to assess paths of improvements and further developments. In fact, although the proposed framework helps advance the theory and gives a valuable tool to practitioners, much remains to be done, since important issues that would deserve special attention have not been adequately investigated yet. In particular, there are several lines of inquiry springing from the overall research which need to be addressed in order to enhance the value of the proposed framework.

A primary avenue regards the completion of the performance measurement system with the key performance indicators for the other three smart city pillars that remained unaddressed in this project, as described in the previous section. Thus, the realization of the indicators of Smart Economy, Smart Governance and Smart People are fundamental objectives to be pursued by future works. However, the importance of such pathway is grander. In fact, as marked out in section 7.3, this work must be the first or N of a continuous improvement process. The indicators composing the system must be periodically updated and renewed according to the cities needs and challenges.

Secondly, the survey developed in chapter 6 highlights the context-specific factors that are mainly recurrent for Italian cities in measuring and monitoring Smart City performances. The analysis lays the foundations for the actual implementation of the monitoring framework proposed by the authors in chapter 5 in the Italian landscape. Actually, the additional information collected enables to acknowledge the context-specific factors that are relevant in Italy and effectively test the framework Italian cities, including the peculiarities of the geographical region. This actual testing and validation phase is considered as a potential avenue of further research.

Finally, the other central priority for future research must be the testing stage for the application of the proposed system in other geographical regions. Again, the room for improvement are incredible. First Italian cities could be involved, on the basis of the context-specific factors identified, then the European ones, and successively new objectives can be explored.

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APPENDICES

INDICATORS OF THE PROPOSED FRAMEWORK

1. SMART ENVIRONMENT

1.1. ENERGY

KPI n 1	**Final energy consumption per capita**
Description	This indicator assesses the final energy consumption of the city taking into account all forms of energy (e.g. electricity, gas, fuels) and for all functions monitored by the city(public transport, buildings, ICT, industry, etc.). The final energy consumption is the energy actually consumed by the end-user. This in contrast with primary energy use, the energy forms found in nature (e.g. coal, oil and gas) which have to be converted (with subsequent losses) to useable forms of energy, a more common indicator for evaluating energy consumption.
Calculation	Total use of final energy (MWh) within a city divided by the amount of residents in city. The result indicates the total energy consumption per year in megawatt hours per capita. The calculation of the indicator can be facilitated from breaking down the energy consumption of various sectors (e.g. buildings, transport, industry, etc.). All forms of energy need to be taken into account, including electricity production, natural gas or thermal energy for heating and cooling and fuels. These will be given in different units of energy (kWh, GJ, m3), but they all have to be calculated or converted to MWh of energy in order to be able to sum up the separately calculated energy generations and achieve the total energy consumption of the city.
Unit of measure	MWh/capita/year
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	This indicator has a quite complex calculation. That is why it might not be always possible to calculate it at city scale.

KPI n 2	Energy intensity
Description	Energy intensity is the ratio between gross inland energy consumption (GIEC) and PPP (power purchasing parity) gross domestic product (GDP), calculated for a calendar year. The indicator measures the energy consumption of an economy and its overall energy efficiency. Cities with more energy intensity per local GDP means that they consume more energy to produce the same amount of goods measured in GDP units.
Calculation	GIEC is calculated as the sum of the gross inland consumption of the five sources of energy: solid fuels, oil, gas, nuclear and renewable sources. It is measured in 1000 tons of oil equivalent (ktoe), while GDP is expressed in millions of euros at the current year market prices. The alternative, in order to monitor trends avoiding the impact of inflation, could be to express GDP at a reference year market prices (e.g. 2010, 2020).
Unit of measure	ktoe/mln euros
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	5
Notes	This indicator has a really complex calculation and implies a very well structured data collection system. That is why it is designed more for future evaluations, while nowadays its measurement might be more feasible at national scale. Moreover, it must be specified that cities with similar economical structures must be considered in comparing this indicator. For example, an industrial city should be compared with another industrial one, a city based on tertiary services with another similar, and so on.

KPI n 3	Energy used in recycling
Description	The indicator assesses the efficiency of the recycling activities within the city, registering the amount of annual energy used in order to cover the benefits coming from recycling activities.
Calculation	Quantity of energy used all the recovery and recycling facilities/Amount of waste entering all the waste recovery and recycling facilities.
Unit of measure	kWh / t
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	5
Notes	This indicator has a quite complex calculation. That is why it might not be always possible to calculate it at city scale.

1.2 ENERGY- ELECTRICITY

KPI n 4	**Electricity production per capita**
Description	This indicator assesses the total value of electricity per capita generated by all functions.
Calculation	Total production of electricity (MWh) within a city divided by the amount of residents in city. The result indicates the total electricity production per year in megawatt hours per capita. The calculation of the indicator can be facilitated from breaking down the energy production deriving from various sources.
Unit of measure	kWh/capita/year
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 5	**Electricity consumption per capita**
Description	This indicator assesses the total value of electricity per capita consumed by all functions.
Calculation	Total consumption of electricity (MWh) within a city divided by the amount of residents in city. The result indicates the total electricity consumption per year in megawatt hours per capita. The calculation of the indicator can be facilitated from breaking down the energy consumption of various sectors (e.g. buildings, transport, industry, etc.).
Unit of measure	kWh/capita/year
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 6	**Electricity in the energy mix**
Description	This indicator assesses the electrification rate of the city, indicating the percentage of electricity in the total energy consumption mix
Calculation	It is calculated as the ratio between the total value of electricity consumption and the total value of final energy consumption within the city. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 7	**Percentage of city population with authorized electrical services**
Description	This indicator shows the number of people with authorized electrical services in the city.
Calculation	It is calculated as the ratio between the number of people with authorized electrical service and the population of the city. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

1.3 ENERGY – FUEL

KPI n 8	**Fuel energy consumption per capita**
Description	This indicator assesses the total value of fuel energy per capita consumed by all functions. In particular, this indicators accounts for petroleum products and oil, natural gas, gasoline, diesel fuel and heating oil. Note that the nuclear component is not included.
Calculation	Total use of fuel energy within a city divided by the amount of residents in city. The result indicates the total energy consumption per year in GJ per capita. The calculation of the indicator can be facilitated from breaking down the energy consumption of various functions. All forms of energy specified in the description need to be taken into account. These will be given in different units of energy (GJ, m3), but they all have to be calculated or converted to GJ of energy in order to be able to sum up the separately calculated energy generations and achieve the total energy consumption of the city.
Unit of measure	GJ
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	This indicator has a quite complex calculation. That is why it might not be always possible to calculate it at city scale.

1.4 ENERGY – GREEN ENERGY

KPI n 9	**Renewable energy generated within the city**
Description	This indicator is the percentage of total energy derived from the renewable systems installed in the city as a share of the city's total energy consumption. Renewable energy shall include both combustible and non-combustible renewables. Non-combustible renewables include geothermal, solar, wind, hydro, tide and wave energy. The combustible renewables include biomass (fuelwood, vegetal waste, ethanol) and animal products (animal materials/waste and sulphite lyes). Municipal waste (waste produced by the residential, commercial and public service sectors that are collected by local authorities for disposal in a central location for the production of heat and/or power) and industrial waste are not considered a renewable source for energy production.
Calculation	The share of renewable energy produced within the city is calculated as the total consumption of electricity generated from renewable sources divided by total energy consumption.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 10	**Percentage of total renewable energy sources (RES) self-supplied**
Description	Self supply refers to green power use by a consumer whereby the consumer owns the renewable electricity generator and is responsible for its maintenance and operation. In this way the consumer is generating and supplying their own green power. This indicator shows the impact of self-supply over the total renewable energy generated annually within the city.
Calculation	It is calculated as the ratio between the amount of renewable electricity self supplied and the total consumption of renewable electricity. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	4
Notes	This indicator has a quite complex calculation. That is why it might not be always possible to calculate it at city scale.

KPI n 11	**RES power installed**
Description	It resumes the overall installed renewable capacity accounting for both residential and utility scale.
Calculation	It represents the cumulate value of MW installed in the city and it is obtained summing all the capacities within the city in the current year plus the cumulate value obtained from the previous years.
Unit of measure	MW
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

1.5 ENERGY STORAGE

KPI n 12	**RES storage capacity installed**
Description	It t resumes the overall RES storage capacity installed at residential scale.
Calculation	It represents the cumulate value of MWh installed in the city and it is obtained summing all the capacities within the city in the current year plus the cumulate value obtained from the previous years.
Unit of measure	MWh
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 13	**Grid storage capacity per total city energy consumption**
Description	This indicator assesses the energy storage capacity of the city's grid and evaluates it as the portion of the overall final energy consumed annually. Note that it refers to the utility scale.
Calculation	It is calculated as the total amount of energy stored annually on the city grids (GJ) divided by the city total final energy consumption (GJ). The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

1.6 ENERGY – W2E

KPI n 14	**Percentage of city's solid waste that is treated in energy-from-waste plants**
Description	The indicator measures the portion of city's solid waste that is treated annually for energy generation.
Calculation	It is calculated as the value of tons of solid waste disposed in energy-from-waste plants divided by the total value of tons of city solid waste generated within the city. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	A similar useful indicator could evaluate the percentage of energy demand recovered by waste treatment, showing the electrical and thermal energy produced from wastewater treatment, solid waste and other liquid waste treatment and other waste heat resources, as a share of the city’s total energy mix for a given year.

1.7 ENERGY – SMART GRID AND BALANCING

KPI n 15	**Average number of electrical interruptions**
Description	The indicator shows the average number of electrical interruptions per customer per year.
Calculation	It shall be calculated as the total number of customer interruptions divided by the total number of customers served. The result shall be expressed as the average number of electrical interruptions per customer per year.
Unit of measure	#customers/year
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	3
Notes	/

KPI n 16	**Average length of electrical interruptions**
Description	The indicator shows the average annual hours of electrical service interruptions per household.
Calculation	It is obtained by summing the number of hours of interruption, multiplying them by the number of households impacted by the interruptions and divide the overall value by the total number of households within the city.
Unit of measure	Hours
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	4
Notes	/

KPI n 17	**Smart meters**
Description	Smart meters play a fundamental role in the development of smart grids. This indicator assesses the diffusion of smart meters within the city.
Calculation	It is calculated as the ratio between the number of smart electricity meters installed and the total number of electricity meters installed. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

1.8 CITY PLANNING – RISK MANAGEMENT

KPI n 18	**Population living in disaster-prone areas**
Description	This indicator evaluates the percentage of inhabitants living in natural hazards (such as cyclones, drought, floods, earthquake, volcanoes and landslides) prone areas.
Calculation	The indicator is calculated as the number of city inhabitants living in natural hazard prone areas divided by the total number of city's inhabitants. The numerator is obtained by using historical and other data on hazards and on vulnerability. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	3
Notes	Note that in some cases the calculation of this indicator could involve a significant area and number of people, especially in developing countries. That is why it might result as the 100% of the population and be more meaningful at national scale.

KPI n 19	**Natural disaster related deaths**
Description	This indicator reports the annual number of deaths per 100,000 inhabitants caused by natural disasters within the city.
Calculation	It is obtained as the number of annual natural disaster related deaths divided by the city's population. Then, the result is multiplied by 100,000.
Unit of measure	#/100,000
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 20	**Disaster risk management in city planning**
Description	The goal of this indicator is to assess whether disaster risk management practices such as for disaster prevention, prediction, control and emergency response are examined in city planning.
Calculation	It evaluates the presence of disaster risk management plans within the city.
Unit of measure	Yes/No
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	1
Notes	/

KPI n 21	**Critical infrastructures**
Description	The indicator assesses the percentage of critical infrastructure present in the city that are at risk due to inadequate construction or placement in areas of non-mitigable risk.
Calculation	It is calculated as the number of infrastructures with inadequate construction or located in hazard prone areas divided by the total number of city's infrastructures. The list of criteria that must be met for adequate construction and data regarding hazard prone areas are provided by the municipality, which keeps track of historical and other data on hazards and on vulnerability .
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

1.9 CITY PLANNING – URBAN PLANNING

KPI n 22	**Brownfield redevelopment**
Description	Brownfield is a term used in urban planning to describe “land which is or was occupied by a permanent structure, including the curtilage of the developed land and any associated fixed surface infrastructure.” (Bosch et al. 2017). Many brownfields are contaminated as a result of previous industrial or commercial uses. Brownfield remediation and regeneration represents a valuable opportunity, not only to prevent the loss of pristine countryside and reduce ground sealing, but also to enhance urban spaces and remediate the sometimes contaminated soils.
Calculation	The indicator is calculated as the brownfield area redeveloped in the last year (km^2) divided by the total brownfield area in the city (km^2). The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City (or District)
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 23	**Green and water spaces**
Description	Green and water spaces are regarded as an index representing the degree of the nature conservation and improving the public health and quality of life as they are directly related to the natural water circulation, environmental purification and the green network. This indicator reflects the ratio of green and water space area from total city land area. Green areas are forest and park areas that are partly or completely covered with grass, trees, shrubs, or other vegetation. Water areas here meaning lakes, ponds, rivers.
Calculation	It is calculated annually with the following formula: ((water areas (km^2) + green space areas (km^2))/total city area (km^2))*100
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 24	**Commercial and industrial activities**
Description	It reports the share of areas designated for commercial and industrial activities within the city.
Calculation	It is calculated as the sum of commercial and industrial areas (km^2) divided by the total city area (km^2). The result shall then be multiplied by 100 and expressed as a percentage. To calculate the numerator the brownfield areas must not be considered.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 25	**Residential areas**
Description	It reports the share of residential areas within the city.
Calculation	It is calculated as the sum of residential areas (km^2) divided by the total city area (km^2). The result shall then be multiplied by 100 and expressed as a percentage. To calculate the numerator the brownfield areas must not be considered, while the informal settlements areas must be considered.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 26	**Transport areas**
Description	It reports the share of areas designated for transport activities within the city. It encompasses all the transport areas: those for public transportation, private vehicles, vehicles sharing and all those concerning pedestrians.
Calculation	It is calculated as the sum of transport areas (km^2) divided by the total city area (km^2). To calculate the numerator the brownfield areas must not be considered.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 27	**Areas for social infrastructures**
Description	It reports the share of areas designated for social infrastructures within the city. Social infrastructures includes assets that accommodate social services.
Calculation	It is calculated as the sum of areas for social infrastructures (km^2) divided by the total city area (km^2). The result shall then be multiplied by 100 and expressed as a percentage. To calculate the numerator the brownfield areas must not be considered.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 28	**Unused Areas**
Description	It reports the share of areas designated for social infrastructures within the city. Social infrastructures includes assets that accommodate social services.
Calculation	It is calculated as the sum of areas for social infrastructures (km^2) divided by the total city area (km^2). The result shall then be multiplied by 100 and expressed as a percentage. To calculate the numerator the brownfield areas must not be considered.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 29	**Basic service proximity**
Description	Basic services such as water, sanitation, drainage, energy, and transport are key ingredients for the economic and social development of urban areas. This indicator concerns the rapid accessibility of basic services. It assesses the share of inhabitants living near at least one basic service.
Calculation	It is calculated as the number of inhabitants having access to a basic service within 300 metres divided by the city population.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 30	**Population density**
Description	Population density is often used as a simple relative measure of how an organism responds to local conditions. If conditions are not good for the species, the density will be low (organisms will have died or moved out of the sampled area), whereas if conditions are good the density will be high (organisms will have reproduced and/or immigrated into the area). In this way, changes in density can provide insight into the natural history of the preferences and tolerances of individuals of the species.
Calculation	It is calculated annually as the number of individuals per unit geographic area, namely number per square meter.
Unit of measure	#/km^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	1
Notes	/

KPI n 31	**Housing located in informal settlements**
Description	Informal settlements, can be defined as residential areas where a group of housing units has been constructed on land to which the occupants have no legal claim, or which they occupy illegally.
Calculation	It is calculated annually as the number of housing constructed in such areas divided by the total number of housing within the city. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

1.10 ECOSYSTEM

KPI n 32	**Number of native species**
Description	Urbanization affects biodiversity through urban sprawl/habitat fragmentation, loss of fertile agricultural lands, and spread of invasive alien species. A loss in biodiversity threatens food supplies, lessens opportunities for recreation and tourism, and impacts a diverse range of medicinal and practical uses, varieties of wood, and energy. It also interferes with essential ecological function, such as carbon sequestration and air filtering. Native species are plants and animals that originated and live in an area without any human intervention. On the contrary, introduced, or non-native species, have been brought to their current locations by humans and often become invasive, or too pervasive for the environment. There are two types of native species: indigenous and endemic. Indigenous species are native species that are found in multiple locations, whereas endemic species are only found in a specific, unique location.
Calculation	Three key taxonomic groups are the most surveyed worldwide, i.e., plants, birds and butterflies. A city is requested to list the number of native species that it has data on. The full list can be found in the User's Manual for the City Biodiversity Index (Borsch et al. 2017)
Unit of measure	# of specie
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	3
Notes	Note that in some cases the calculation of this indicator could involve a significant area and number of people, especially in developing countries. That is why it might result as the 100% of the population and be more meaningful at national scale.

KPI n 33	**Ecosystem protected areas**
Description	A protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values.
Calculation	The indicator is reported annually and is calculated as the surface (marine and terrestrial) of protected areas (km^2) divided by the entire municipality surface area (km^2). The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 34	**Urban ecological footprint**
Description	The Ecological Footprint as defined by the Ecological Footprint standards calculates how much biologically productive area is required to produce the resources required by the human population and to absorb humanity's carbon dioxide emissions. In other words, it is a geographical measure of an urban population's demand on natural capital. Approximately 90 percent of all leading Ecological Footprint practitioners worldwide have joined Global Footprint Network and have agreed to adhere to these standards and to use a common set of data.
Calculation	The Ecological Footprint of a person is calculated by adding up all of people's demands that compete for biologically productive space, such as cropland to grow potatoes or cotton, or forest to produce timber or to sequester carbon dioxide emissions. All of these materials and wastes are then individually translated into an equivalent number of global hectares. To accomplish this, an amount of material consumed by that person (tons per year) is divided by the yield of the specific land or sea area (annual tons per hectare) from which it was harvested, or where its waste material was absorbed. The number of hectares that result from this calculation are then converted to global hectares using yield and equivalence factors. The sum of the global hectares needed to support a person is that person's total Ecological Footprint. The Ecological Footprint of a group of people, such as a city or nation, is simply the sum of the Ecological Footprint of all the residents of that city or nation.
Unit of measure	Global hectares (gha)
Perimeter of analysis	City (or Nation)
Frequency of reporting	Yearly
Scoring	5
Notes	Note that in some cases the calculation of this indicator could involve a significant area and number of people, especially in developing countries. That is why it might result as the 100% of the population and be more meaningful at national scale.

KPI n 35	**Climate resilience strategy**
Description	Urban areas in Europe and worldwide are increasingly experiencing the pressures arising from climate change and are projected to face aggravated climate-related impacts in the future. Several cities and towns across Europe are already pioneering adaptation action and many others are taking first steps to ensure that cities remain safe, livable and attractive centers for innovation, economic activities, culture and social life. This indicator assesses to what extent the city has a resilience strategy and action plan.
Calculation	The indicator provides a qualitative measure and is rated on a seven-point Likert scale. 1. No action has been taken yet 2. The ground for adaptation has been prepared 3. Risks and vulnerabilities have been assessed 4. Adaptation options have been identified 5. Adaptation options have been selected 6. Adaptation options are being implemented 7. Monitoring and evaluation is being carried out.
Unit of measure	Likert
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 36	**Urban heat island**
Description	This indicator focuses on the urban heat island (UHI) effect, the difference in air temperature between the city and its surroundings. The UHI effect is caused by the absorption of sunlight by (stony) materials, the lack of evaporation and the emission of heat caused by human activities. The effect is at its highest point after sunset and can reach up to 9 ℃ in e.g. Rotterdam. Due to the UHI effect, urban areas experience more heat stress than the countryside.
Calculation	Whether there is one or several measurement stations in the built environment, compare the air temperature measurements of these stations with a station outside the city which functions as a reference station, and look for the largest temperature difference (hourly average) during the summer months.
Unit of measure	°C UHImax
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

1.11 ECOSYSTEM – WATER MANAGEMENT

KPI n 37	**Water consumption**
Description	Water management and supply of safe drinking water have become a global issue. Due to changes in the climate, there has been an increase of either extreme dry and warm seasons in some countries or rainy seasons connected with floods in other areas. Water scarcity varies greatly between countries, even between regions inside the countries, even between regions inside the country.
Calculation	It shall be calculated as the total amount of the city’s water consumption in liters per day divided by the total city population.
Unit of measure	Litre/capita
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 38	**Population served by wastewater collection**
Description	The treatment of urban waste water is fundamental to ensuring public health and environmental protection. Urban waste water treatment in all parts of Europe has improved over recent decades. This indicator assesses the annual percentage of population connected to urban waste water treatment accounting for primary, secondary and tertiary treatment.
Calculation	It shall be calculated as the number of people served by wastewater collection divided by the city population.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 39	**Water losses**
Description	Before reaching the users, a part of the water supplied might be lost through leakage or illegal tapping. In cities with old and deteriorating water reticulation systems, a substantial proportion of piped water may be lost through cracks and flaws in pipes – for example up to 30 per cent of water is lost in this way in some countries in Eastern Europe. The percentage of water loss (unaccounted for water) represents the percentage of water that is annually lost from treated water entering distribution system and that is accounted for and billed by the water provider. This includes actual water losses, e.g. leaking pipes, and billing losses, e.g. delivered through informal or illegal connection.
Calculation	It shall be calculated as the volume of water supplied minus the volume of customer billed water divided by the total volume of water supplied. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 40	**Population with potable water supply service**
Description	The lack of access to safe water and sanitation is one of the main challenges related to water. This indicator aims at monitoring the percentage of city population with potable water supply service.
Calculation	It shall be calculated as the number of people served by potable water supply service divided by the city population. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 41	**Water service interruptions**
Description	The indicator shows the average annual hours of water service interruptions per household.
Calculation	It is obtained by summing the number of hours of interruption, multiply them by the number of households impacted by the interruptions and divide the overall value by the total number of households within the city.
Unit of measure	hours
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	3
Notes	/

KPI n 42	**Smart water meters**
Description	Smart water meters play a fundamental role in the development of smart grids. This indicator assesses the diffusion of smart water meters within the city.
Calculation	It shall be calculated as the number of smart water meters installed divided by the total number of water meters installed within the city. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 43	**Real-time water quality tracking**
Description	The indicator assesses the percentage of annual drinking water tracked by real-time, water quality monitoring station.
Calculation	It shall be calculated as the amount of drinking water that has undergone water quality monitoring divided by the total amount of drinking water distributed. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

1.12 ECOSYSTEM – OTHER RESOURCES USAGE

KPI n 44	**Domestic material consumption**
Description	The indicator ‘domestic material consumption’ (DMC) considers the domestic material extraction (i.e. the amount of raw material extracted from the natural environment, except for water and air), including both imports (added) and exports (deducted) through their simple product weight when crossing the city limits. A city with almost no domestic extraction and importing all necessary resources indirectly in the form of mainly finished products will have a much lower DMC compared to a resource rich city.
Calculation	Domestic Material Consumption (DMC) is calculated as the Direct Material Input (DMI) minus exports. DMI measures the direct input of materials for the use in the economy and equals Domestic Extraction (DE) plus imports.
Unit of measure	tons/capita
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

1.13 ECOSYSTEM – GHG EMISSIONS

KPI n 45	**CO2 emissions**
Description	Greenhouse gases (GHGs) are gases in the atmosphere that absorb infrared radiation that would otherwise escape to space; thereby contributing to rising surface temperatures. There are six major GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The warming potential for these gases varies from several years to decades to centuries. CO_2 accounts for a major share of Green House Gas emissions in urban areas. The main sources for CO_2 emissions are combustion processes related to energy generation and transport. Tons of CO_2 emissions per capita can therefore considered a useful indicator to assess the contribution of urban development on climate change.
Calculation	The indicator is calculated as the direct (operational) reduction of the CO_2 emissions over a calendar year: before the project and after the project. The result will be divided by the CO_2 emissions before the project, and then it is multiplied by 100 to express the result as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

1.14 POLLUTION

<table>
<tr><th>KPI n 46</th><th>Air quality index</th></tr>
<tr><td>Description</td><td>Air quality is expressed in the concentration of major air pollutants. At this moment from a human health perspective most important are particulates (PM10, PM2.5), NO_2 (as indicator of traffic related air pollution) and ozone (important for smog). The concentration levels of these pollutants together define the air quality. For this indicator we use the year average air quality index. It is a distance to target indicator that provides a relative measure of the annual average air quality in relation to the European limit values (annual air quality standards and objectives from EU directives). If the index is higher than 1: for one or more pollutants the limit values are not met. If the index is below 1: on average the limit values are met.</td></tr>
<tr><td>Calculation</td><td>
<table>
<tr><th>Pollutant</th><th>Target value / limit value</th><th>Subindex calculation</th></tr>
<tr><td>NO_2</td><td>Year average is 40 µg/m3</td><td>Year average / 40</td></tr>
<tr><td>PM10</td><td>Year average is 40 µg/m3</td><td>Year average / 40</td></tr>
<tr><td>PM10 daily</td><td>Max. number of daily averages above 50 µg/m3 is 35 days</td><td>Log(number of days+1) / Log(36)</td></tr>
<tr><td>Ozone</td><td>25 days with an 8-hour average value >= 120 µg/m3</td><td>Number of days with 8-hour average >=120 / 25</td></tr>
<tr><td>SO_2</td><td>Year average is 20 µg/m3</td><td>Year average / 20</td></tr>
<tr><td>Benzene</td><td>Year average is 5 µg/m3</td><td>Year average / 5</td></tr>
</table>
The overall city index is the average of the sub-indices for NO_2, PM10 (both year average and the number of days >=50 µg/m3 sub-index) and ozone for the city background index. For the traffic year average index the averages of the sub-indices for NO_2 and PM10 (both) are being used. The other pollutants (including PM2.5) are used in the presentation of the city index if data are available, but do not enter the calculation of the city average index. They are treated as additional pollutants like in the hourly and daily indices. The main reason is that not every city is monitoring this full range of pollutants.</td></tr>
<tr><td>Unit of measure</td><td>%</td></tr>
<tr><td>Perimeter of analysis</td><td>City</td></tr>
<tr><td>Frequency of reporting</td><td>Yearly</td></tr>
<tr><td>Scoring</td><td>4</td></tr>
<tr><td>Notes</td><td>/</td></tr>
</table>

KPI n 47	**PM 2.5 concentration**
Description	Fine particulate matter can cause major health problems in cities. According to the WHO (Borsch et a. 2017), any concentration of particulate matter (PM) is harmful to human health. PM is carcinogenic and harms the circulatory system as well as the respiratory system. As with many other air pollutants, there is a connection with questions of environmental justice, since often underprivileged citizens may suffer from stronger exposure. The evidence on PM and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations in both developed and developing countries. The range of health effects is broad, but are predominantly to the respiratory and cardiovascular systems.
Calculation	The indicator is obtained dividing the total PM2.5 emissions (g) by the city population.
Unit of measure	g/capita
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 48	**NOx concentration**
Description	Nitrogen oxides (NO and NO_2) are major air pollutants, which can have significant impacts on human health and the environment. NO contributes to ozone layer depletion and, when exposed to oxygen, can transform into NO_2. NO_2 contributes to the formation of photochemical smog and at raised levels can increase the likelihood of respiratory problems. Nitrogen dioxide inflames the lining of the lungs, and it can reduce immunity to lung infections. This can cause problems such as wheezing, coughing, colds, flu and bronchitis. Increased levels of nitrogen dioxide can have significant impacts on people with asthma because it can cause more frequent and more intense attacks. NO_2 chemically transforms into nitric acid and contributes to acid rain. Nitric acid can corrode metals, fade fabrics, and degrade rubber. When deposited, it can also contribute to lake acidification and can damage trees and crops, resulting in substantial losses. Nitrogen dioxide is part of the exhaust gases of motor vehicles, but also emanates from other combustion processes, related for example to domestic heating and industrial processes.
Calculation	The indicator is obtained dividing the total NOx emissions (g) by the city population.
Unit of measure	g/capita
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 49	**Air quality monitoring stations**
Description	It is fundamental to monitor the air quality within the city. This indicator assesses the number of real-time remote air quality monitoring stations per squared kilometres (km^2).
Calculation	It is simply calculated as the total number of real-time remote air quality monitoring stations divided by the city's land area in km^2.
Unit of measure	#/km^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

1.15 POLLUTION – NOISE

KPI n 50	**Noise pollution**
Description	Prolonged exposure to noise can lead to significant health effects, both physical and mental. This indicator assesses the number of inhabitants exposed to noise >55 dB(A) at day and night time.
Calculation	It is calculated with the following formula: (#inhabitants exposed to noise > 55dB(a)/total number of inhabitants)*100. Noise pollution shall be calculated by mapping the noise level during the day (Ln) likely to cause annoyance, identifying the areas of the city where Ln is greater than 55 dB(A) and estimating the population of those areas as a percentage of the total city population. The result shall be expressed as the percentage of the population affected by noise pollution.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	2
Notes	/

1.16 WASTE

KPI n 51	**Solid waste collection**
Description	The proper discharge, transportation and treatment of solid waste is one of the most important components of life in a city and one of the first areas in which governments and institutions should focus. Solid waste systems contribute in many ways to public health, the local economy, the environment, and the social understanding and education about the latter. A proper solid waste system can foster recycling practices that maximize the life cycle of landfills and create recycling micro-economies; and it provides alternative sources of energy that help reduce the consumption of electricity and/or petroleum based fuels. This indicator measures the percentage of city population with regular solid waste collection.
Calculation	It is calculated as the number of people served by regular solid waste collection divided by the total city population. The result shall then be multiplied by 100 and expressed as a percentage.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	3
Notes	/

KPI n 52	**Municipal solid waste**
Description	This indicator provides a measure of how much waste a city is producing and the level of service a city is providing for its collection. Municipal waste shall refer to waste collected by or on behalf of municipalities. The data shall only refer to the waste flows managed under the responsibility of the local administration including waste collected on behalf of the local authority by private companies or regional associations founded for that purpose. Municipal waste should include waste originating from: — households; — commerce and trade, small businesses, office buildings and institutions (e.g. schools, hospitals, government buildings). The definition should also include: — bulky waste (e.g. white goods, old furniture, mattresses); — garden waste, leaves, grass clippings, street sweepings, the content of litter containers, and market cleansing waste, if managed as waste; — waste from selected municipal services, i.e. waste from park and garden maintenance, waste from street cleaning services (e.g. street sweepings, the content of litter containers, market cleansing waste), if managed as waste. The definition shall exclude: — waste from municipal sewage network and treatment; — municipal construction and demolition waste.
Calculation	The total collected municipal solid waste per capita shall be expressed as the total municipal solid waste produced in the municipality per person. This indicator shall be calculated as the total amount of solid waste (household and commercial) generated annually (in tons) divided by the total city population.
Unit of measure	tons/capita
Perimeter of analysis	City
Frequency of reporting	Monthly
Scoring	3
Notes	/

KPI n 53	**Waste drop-off centers telemetering**
Description	This indicator measures the percentage of waste drop-off centres equipped with telemetering.
Calculation	It is calculated as the number of waste drop-off centres (containers) for garbage disposal equipped with telemetering devices divided by the total waste drop-off centres within the city.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 54	**Sensor-enabled public garbage bins**
Description	This indicator measures the percentage of public garbage bins that are sensor-enabled.
Calculation	It is calculated as the number of public garbage bins that are sensor-enabled divided by the total number of public garbage bins in the city.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

1.17 WASTE – RECYCLING AND REUSE

KPI n 55	**Recycling rate**
Description	Many cities generate more solid waste than they can dispose of. Higher levels of municipal waste contribute to greater environmental problems and therefore levels of collection, and also methods of disposal, of municipal solid waste are an important component of municipal environmental management. Solid waste systems contribute in many ways to public health, the local economy, the environment, and the social understanding and education about the latter. A proper solid waste system can foster recycling practices that maximize the life cycle of landfills and create recycling microeconomies; and it provides alternative sources of energy that help reduce the consumption of electricity and/or petroleum based fuels.
Calculation	The percentage of city's solid waste that is recycled shall be calculated as the total amount of the city’s solid waste that is recycled in tonnes divided by the total amount of solid waste produced in the city in tonnes. The result shall then be multiplied by 100 and expressed as a percentage. Recycled materials shall denote those materials diverted from the waste stream, recovered, and processed into new products following local government permits and regulations. Hazardous waste produced in the city and recycled shall be reported separately.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 56	**Hazardous waste recycled**
Description	Hazardous waste is a waste with properties that make it dangerous or capable of having a harmful effect on human health or the environment. It is generated from many sources, ranging from industrial manufacturing process wastes to batteries and may come in many forms, including liquids, solids gases, and sludges.
Calculation	The percentage of city's solid waste that is recycled shall be calculated as the total amount of the city’s hazardous waste that is recycled in tonnes divided by the total amount of hazardous waste produced in the city in tonnes. The result shall then be multiplied by 100 and expressed as a percentage. Recycled materials shall follow local government permits and regulations
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

2. SMART LIVING

2.1 BUILDING DATA

KPI n 1	**Total number of residential buildings**
Description	The indicator assesses the total number of residential buildings that are present in the city at current year, considering both private houses and condominiums.
Calculation	The indicator is calculated as the total number of residential buildings within the city or district.
Unit of measure	#
Perimeter of analysis	City (or district)
Frequency of reporting	Yearly
Scoring	1
Notes	/

KPI n 2	**Total number of public buildings**
Description	Public building refers to a government-owned or leased building that functions as a municipal and administrative office, library, public recreation centre, hospital, school, fire station or police station.
Calculation	The indicator is calculated as the total number of public buildings within the city.
Unit of measure	#
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	1
Notes	/

KPI n 3	**Total number of commercial buildings**
Description	Commercial buildings refers to private units that are used for commercial purposes such as shopping centres, supermarkets, private offices, galleries, shops.
Calculation	It is calculated as the total number of commercial buildings within the city or district.
Unit of measure	#
Perimeter of analysis	City (or district)
Frequency of reporting	Yearly
Scoring	1
Notes	/

KPI n 4	**Average age of the buildings**
Description	The indicator is a measure of the age and innovativeness of the district or city.
Calculation	Sum of the age of construction of the all the buildings divided by total number of buildings of the district or city.
Unit of measure	Years
Perimeter of analysis	City (or district)
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 5	**Number of historic and artistic buildings and views**
Description	The indicator is a measure of the historic and artistic attractiveness of the district or city.
Calculation	Number of historic and artistic buildings and views in the city.
Unit of measure	#
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

2.2 BUILDING DATA – ENERGY

KPI n 6	**Thermal energy consumption of public buildings**
Description	The indicator considers the thermal final energy consumed in a year by public buildings. Public building refers to a government-owned or leased building that functions as a municipal and administrative office, library, recreation centre, hospital, school, fire station or police station.
Calculation	It is calculated as total thermal energy consumed by public buildings within a city per year divided by total floor space of these buildings.
Unit of measure	MWh / m^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	The indicator can be furtherly split considering the final use of the energy consumption, which consists in heating, cooling, ventilation, hot water and lighting.

2.3 BUILDING DATA – ELECTRICITY

KPI n 7	**Electricity consumption of public buildings**
Description	The indicator considers the electrical energy consumed in a year by public buildings. Public building refers to a government-owned or leased building that functions as a municipal and administrative office, library, recreation centre, hospital, school, fire station or police station.
Calculation	It is calculated as total electrical energy consumed by public buildings within the city per year divided by total floor space of these buildings.
Unit of measure	MWh / m^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	The indicator can be furtherly split considering the final use of the energy consumption, which consists in heating, cooling, ventilation, hot water and lighting.

2.4 BUILDING DATA – GREEN ENERGY

KPI n 8	**Green "prosumer" residential buildings**
Description	A green prosumer is a building that consumes and produces energy from Renewable Energy Sources (RES) plants, either for self-consumption or consumption by others. Thus, it is connected in a bidirectional flow with the grid.
Calculation	Number of residential buildings within the city which produce and consume green energy and are connected to the grid divided by total number of residential buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 9	**Green "prosumer" public buildings**
Description	A green prosumer is a building that consumes and produces energy from Renewable Energy Sources (RES) plants, either for self-consumption or consumption by others. Thus, it is connected in a bidirectional flow with the grid.
Calculation	Number of public buildings within the city which produce and consume green energy and are connected to the grid divided by total number of public buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 10	**Green "prosumer" commercial buildings**
Description	A green prosumer is a building that consumes and produces energy from Renewable Energy Sources (RES) plants, either for self-consumption or consumption by others. Thus, it is connected in a bidirectional flow with the grid.
Calculation	Number of commercial buildings within the city which produce and consume green energy and are connected to the grid divided by total number of commercial buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

2.5 BUILDING DATA – ENERGY STORAGE

KPI n 11	**Residential buildings with an energy storage system**
Description	An energy storage system (ESS) is an infrastructure such as a lithium-ions battery that permits to storage part of the energy produced by a renewable energy source plant, when the production of energy is higher that the consumption.
Calculation	Number of residential buildings within the city which produce and consume green energy and have installed an energy storage system divided by total number of residential buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 12	**Public buildings with an energy storage system**
Description	An energy storage system (ESS) is an infrastructure such as a lithium-ions battery that permits to storage part of the energy produced by a renewable energy source plant, when the production of energy is higher that the consumption.
Calculation	Number of public buildings within the city which produce and consume green energy and have installed an energy storage system divided by total number of public buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 13	**Commercial buildings with an energy storage system**
Description	An energy storage system (ESS) is an infrastructure such as a lithium-ions battery that permits to storage part of the energy produced by a renewable energy source plant, when the production of energy is higher that the consumption.
Calculation	Number of commercial buildings within the city which produce and consume green energy and have installed an energy storage system divided by total number of commercial buildings within the city at current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

2.6 BUILDING DATA – ENERGY EFFICIENCY

KPI n 14	**BEMS in public buildings**
Description	The indicator aims to evaluate the presence of Building energy management systems (BEMS) in public buildings. BEMS technological infrastructures to optimize energy management such as smart meters and monitoring and regulation ICT solution devices for temperature, solar radiation, CO_2 emission and energy consumption in lighting.
Calculation	It is calculated as the number of public buildings within the city with BEMS divided by total number of public buildings within the city in current year.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 15	**Public building sustainability certifications**
Description	Buildings with Sustainability certifications generally use less energy and water, increase the recycling levels and are more comfortable for occupants. Only sustainability certifications for ongoing operations and maintenance are considered. Standards to be included are: BREEAM, LEED, CASBEE, BOMA BEST, BCA Green Mark and Passive House (Smiciklas 2019). Other standards that are equivalent to the above can be reported. Certifications for design should not be included as the design stage normally is only 5-10% of a buildings total life cycle impact.
Calculation	Area of public buildings with sustainability certification to a recognized standard in current year divided by total area of public buildings. Data can be sourced from the facilities group within the city and through the websites of the certification agencies such as BREEAM, LEED and CASBEE (Smiciklas 2019).
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 16	**Residential buildings with "energetic class A" or higher levels**
Description	The concept of energetic class of a building is based on the idea that, for each building, it is possible to calculate accurately defined indexes of energetic performance regarding heating, sanitary water, climatization and ventilation. The overall values of the indexes defines the energetic class of the building, which can have the following values: A+++ (the most energy efficient), A++, A+, A, B,C; D, E, F or G (the least energy efficient).
Calculation	Number of residential buildings explicitly classified as building with "energetic class A" or higher levels in the city or district at the end of the year divided by total number of residential buildings in the city or district. If the energetic class of a building is not explicitly declared by authorized entities, the building is not considered as building of "energetic class A".
Unit of measure	%
Perimeter of analysis	City (or district)
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 17	**Public buildings with "energetic class A" or higher levels**
Description	The concept of energetic class of a building is based on the idea that, for each building, it is possible to calculate accurately defined indexes of energetic performance regarding heating, sanitary water, climatization and ventilation. The overall values of the indexes defines the energetic class of the building, which can have the following values: A+++ (the most energy efficient), A++, A+, A, B,C; D, E, F or G (the least energy efficient).
Calculation	Number of public buildings explicitly classified as building with "energetic class A" or higher levels in the city at the end of the year divided by total number of public buildings in the city or district. If the energetic class of a building is not explicitly declared by authorized entities, the building is not considered as building of "energetic class A".
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 18	**New buildings with energetic class A or higher levels**
Description	The indicator considers the percentage of new residential, public and commercial buildings that have been built with energetic class A or higher levels. Buildings are considered new if they have been built within the last 5 years from the year of the indicator reporting.
Calculation	It is calculated as the number of new buildings built within 5 years with energetic class A or higher levels divided by total number of new buildings built within the last 5 years in the city. Residential, public and commercial buildings are counted. Data can be sourced from dedicated city departments.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 19	**Buildings refurbished to higher energetic class**
Description	The indicator evaluates the percentage of buildings refurbished that, thanks to the intervention, have increased their energetic class. Therefore the refurbishment has improved energy efficiency and lessened the environmental impacts. Only the refurbishments of the last 5 years from the year of the indicator reporting are counted.
Calculation	It is calculated as the number of buildings that, within the last 5 years, have been refurbished to higher energetic class divided by total number of buildings refurbished within the last 5 years in the city. Residential, public and commercial buildings are counted. Data can be sourced from dedicated city departments.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

2.7 BUILDING DATA – CONTROL & AUTOMATION INFRASTRUCTURE

KPI n 20	**Public buildings equipped for monitoring indoor air quality**
Description	The monitoring of indoor air quality includes primary pollutants such as CO, Benzene, Acetaldehyde and formaldehyde and it is done through appropriate sensors and meters.
Calculation	Total number of public buildings equipped to monitor indoor air quality at current year divided by total number of public buildings in the city. Data can be sourced from the local authorities, officials, or the Ministry or Department responsible for public buildings.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

2.8 BUILDING DATA – PEOPLE WITH SPECIAL NEEDS

KPI n 21	**Public buildings completely accessible by persons with special needs**
Description	Public buildings are completely accessible by persons with special needs if they guarantee all these requirements: accessible parking spaces, accessible main entrance, automatic doors, sufficient light, accessible washrooms and elevators to all floors.
Calculation	Number of public buildings completely accessible by persons with special needs at current year divided by total number of public buildings in the city. Data can be sourced from local authorities, officials, or the Ministry or Department responsible for public buildings.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 22	**Barrier-free areas in public buildings**
Description	The indicator measures the share of squared metres of public buildings that are accessible by persons with special needs.
Calculation	The indicator is calculated as the squared metres accessible by persons with special needs in public buildings at current year divided by total squared metres of public buildings in the city.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

2.9 PUBLIC LIGHTING

KPI n 23	**Electricity consumption of public street lighting**
Description	The indicator measures the electric energy consumption for public street lighting per kilometre of lighted street. More efficient public street lighting systems have reduced maintenance costs, improved public safety and reduced crime rates, improved road and traffic safety and increased economic productivity.
Calculation	Total electricity consumption of public street lighting in a year in the city divided by total length of streets where lights are present
Unit of measure	kWh / Km
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 24	**Light performance management system in public street lighting**
Description	Light performance management system refers to the ability to monitor light points, set schedules for switching off/on and adjust light levels by dimming with an ICT-based system, which is connected via a communication network to the light points. A light point is any single source of public street lighting, such as a street light, light pole or street lamp.
Calculation	Number of light points of public street lighting within the city controlled by a light performance management system divided by total number light points of the city. Data can be sourced from city departments or ministries responsible for street lighting inventory and street light management.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 25	**New installed and refurbished public lighting systems**
Description	The new installations or the refurbishment of existing street light systems are considered in this indicator if they bring to improve energy efficiency of the street lighting system, for example upgrading ballasts or the use of the LED technology. A light point is any single source of public street lighting, such as a street light, light pole or street lamp. Just the new installations and the refurbishments done within the last 5 years from the year of the indicator reporting are considered.
Calculation	Number of refurbished and newly installed light points within the last 5 years in the city divided by total number of light points in the city. Data can be sourced from city departments or ministries responsible for street lighting inventory.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 26	**Number of service suspensions in public lighting**
Description	The indicator is a measure of the quality of the lighting service in the district or city and assesses the number of service suspensions in public lighting in the city in a year.
Calculation	It is calculated as the number of service suspensions of public lighting in a year in the district or city.
Unit of measure	#
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 27	**Average duration of service suspensions in public lighting**
Description	The indicator is a measure of the quality of the lighting service in the district or city and assesses the average duration of service suspensions in public lighting in the city in a year.
Calculation	It is calculated as the average duration of service suspensions of public lighting in a year in the district or city.
Unit of measure	Minutes
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 28	**Maintenance costs associated with public lighting**
Description	The indicator assesses the public lighting costs for maintenance in the city at current year
Calculation	amount of costs of maintenance associated with public lighting during a year divided by kilometres of the city lighted.
Unit of measure	€ / km
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

2.10 CONDITION PROFILING

KPI n 29	**Durations exposure to daylight during winter**
Description	The indicator is a measure of the daylight exposure of the city during winter period, therefore from January 1st to March 20th plus from December 21st to December 31st for the northern Hemisphere.
Calculation	It is calculated as the average of the amount of time with daylight in the city during winter. It is important to collect the data of duration exposure to daylight in every day of the considered period, in order to have a robust and consistent sample for calculating the average.
Unit of measure	hours / day
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 30	**Durations exposure to daylight during summer**
Description	The indicator is a measure of the daylight exposure of the city during summer period, therefore from June 21st to September 22nd for the northern Hemisphere.
Calculation	It is calculated as the average of the amount of time with daylight in the city during summer. It is important to collect the data of duration exposure to daylight in every day of the considered period, in order to have a robust and consistent sample for calculating the average.
Unit of measure	hours / day
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 31	**Daily average temperature registered during winter**
Description	The indicator is a measure of the daily average temperature registered in the city during winter period, therefore from January 1st to March 20th plus from December 21st to December 31st for the northern Hemisphere.
Calculation	It is calculated as the average of the daily average temperature registered in the city during winter. It is important to collect the data of the average temperature registered in the city in every day of the considered period, in order to have a robust and consistent sample for calculating the average.
Unit of measure	Celsius degrees / day
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 32	**Daily average temperature registered during summer**
Description	The indicator is a measure of the daily average temperature registered in the city during summer period, therefore from June 21st to September 22nd for the northern hemisphere.
Calculation	It is calculated as the average of the daily average temperature registered in the city during summer. It is important to collect the data of duration exposure to daylight in each day of the considered period, in order to have a robust and consistent sample for calculating the average.
Unit of measure	Celsius degrees / day
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

3. SMART MOBILITY

3.1 INFRASTRUCTURE

KPI n 1	**Marked pedestrian crossings equipped with accessible pedestrian signals**
Description	The indicator evaluates the percentage of marked pedestrian crossings equipped with accessible pedestrian signals. Accessible pedestrian signals are devices that communicate when a crossing is safe or not to enter either using visual, audible and/or vibrotactile communication.
Calculation	The indicator is calculated as the number of marked pedestrian crossing equipped with accessible pedestrian signals divided by total number of marked pedestrian crossings.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 2	**City streets covered by real-time online traffic alerts and information**
Description	The indicator assesses the percentage of city streets covered by real-time online traffic alerts and information. There should be considered all local roads, streets and major and minor arterial roads of the city. "Real-time" traffic alerts and information corresponds to traffic information that is instantaneously available and reflects current traffic levels at any given time.
Calculation	Length of streets (in kilometres) within the city covered by real-time online traffic alerts and information divided by total length of all the streets (in kilometres) within city boundaries. Data can be sourced from dedicated city departments, or institutions that manage and communicate information regarding traffic of a particular region.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 3	**Percentage of traffic lights that are intelligent/smart**
Description	Intelligent/smart traffic lights are traffic light systems that utilize ICT technologies and algorithms to control vehicle and pedestrian traffic flow. Multiple traffic lights at the same intersection for traffic heading in the same direction are counted as a single traffic light.
Calculation	It is calculated as the number of traffic lights in the city that are intelligent or smart divided by total number of traffic lights in the city. Data can be sourced from dedicated city departments.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 4	**Pedestrian infrastructure**
Description	The indicator assesses the percentage of the city designated as a pedestrian or car free zone. automobile or truck traffic is prohibited (except for emergency vehicles or occasional deliveries or taxis).
Calculation	Total area of pedestrian or car free zones (in squared kilometres) divided by total city area (in squared kilometres). Data can be sourced from city Geographical Information Systems (GIS) data or city planning departments.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 5	**Road density**
Description	It considers the ratio between the kilometres of public roads (for cars) and the total squared kilometres of the area of the city. It is a measure of the space used for road mobility.
Calculation	It is calculated as total kilometres of public roads within the city divided by total squared kilometres of city area
Unit of measure	Km / km^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 6	**Periodic maintenance of roads**
Description	Average number of interventions for periodic road maintenance in the last 5 years per each public road.
Calculation	It is calculated as the sum of the interventions for road maintenance in the last 5 years, divided by total number of public roads in the city.
Unit of measure	Ratio
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

3.2 INFRASTRUCTURE- BIKE

KPI n 7	**Length of bike route network**
Description	The indicator assesses the length of the bike route network per 100 000 population. The bike route network includes bicycle lanes and paths. Bicycle lanes refer to part of a carriageway designated for cycles and distinguished from the rest of the road by markings. Bicycle paths are an independent road designated just for cycles.
Calculation	Total kilometres of bicycle paths and lanes divided by one 100 000th of the city's total population. Data can be sourced from dedicated city departments.
Unit of measure	km per 100 000 inhabitants
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 8	**Cycle lanes availability**
Description	The indicator measures the ratio between the length of the bike route network and the length of public roads (for cars). It is a solid indicator of the physical availability of cycling infrastructure in comparison to the infrastructure for cars, the mode of transport it wants to replace.
Calculation	Total kilometres of bicycle paths and lanes divided by total kilometres of streets for conventional transportation (cars). Data can be sourced from dedicated city departments.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 9	**Bike sharing coverage**
Description	The indicator assesses the availability of bicycles for bike sharing, considering all the different companies and typologies that are present in the city, in comparison with city total population.
Calculation	It is calculated as the number of bikes available for bike sharing in the city divided by total city population. Data can be found from private companies that are bike sharing providers and/or from dedicated city departments.
Unit of measure	Ratio
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

3.3 EV-CHARGING INFRASTRUCTURE

KPI n 10	**Public charging stations for e-vehicles in the city area**
Description	Electric vehicles include cars (BEVs or PHEVs), buses and motorcycles that runs fully or partially on a battery-powered electric motor. A charging station is publicly accessible equipment that supplies electric energy for recharging battery electric vehicles. A public charging station is for example a public parking area and can be composed by 1 or more charging points.
Calculation	Total number of public charging stations for e-vehicles in the city divided by one 100th of total city area. A station with more changing points is counted as 1.
Unit of measure	# / 100 km^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 11	**Public charging points for e-vehicles in the city area**
Description	Electric vehicle include cars (BEVs or PHEVs), buses and motorcycles that runs fully or partially on a battery-powered electric motor. A charging point is each single wall-box or infrastructure that recharges battery electric vehicles. One or more charging points compose a charging station.
Calculation	Total number of public charging points for e-vehicles in the city divided by total one 100th of total city area. 10 charging points (i.e. 10 wall-boxes) that are in the same unique charging station (i.e. public parking area) should be counted as 10.
Unit of measure	# / 100 km^2
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

3.4 INFRASTRUCTURE – PARKING AREAS

KPI n 12	**Public parking spaces equipped with e-payment systems**
Description	the indicator assesses the percentage of public parking spaces equipped with e-payment systems. Public parking lots have to be considered by their capacity, and street parking have to be counted by individual paid spaces. An e-payment system is a way of paying for goods and services through an electronic medium without the use of cash; Examples are credit cards or online/mobile applications.
Calculation	Number of public parking spaces equipped with an e-payment system as a payment method divided by total number of public parking spaces in the city. Data can be sourced from dedicated city departments or from organisations (public or private) that handle e-payment systems in the city for public parking.
Unit of measure	%
Perimeter of analysis	District
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 13	**Public parking spaces equipped with real-time availability systems**
Description	The indicator assesses the percentage of public parking spaces equipped with real-time availability systems. Public parking lots have to be considered by their capacity, and street parking have to be counted by individual paid spaces. Real-time availability systems for public parking spaces include any form of technology that provides instantaneous information on the availability of public parking spaces, through mobile and/or online applications.
Calculation	It is calculated as the number of public parking spaces that are equipped with real-time availability systems divided by total number of public parking spaces in the city. Data can be sourced from dedicated city departments.
Unit of measure	%
Perimeter of analysis	District
Frequency of reporting	Yearly
Scoring	3
Notes	/

3.5 INFRASTRUCTURE – PUBLIC TRANSPORTATION

KPI n 14	**Length of public transport system**
Description	Public transport includes rail, metro, buses, tramways, buses and other passenger transport services inside the city. If possible, data from each type of transport system should be included and listed individually.
Calculation	It is calculated as the total length (in kilometres) of the public transport systems operating within the city. Transport systems covering the same route have to be counted separately. For example, if a bus and a tram cover the same 1-km route, this counts for 2 km.
Unit of measure	Km
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 15	**Public transport lines equipped with a publicly accessible real-time system**
Description	The indicator defines the percentage of public transport lines equipped with a publicly accessible real-time system. A real-time system gives timely information on transit usage and current volumes of users on public transport lines, with the aim of planning transportation routes and modes in the most efficient way. The information provided should be available to the public to allow access for all citizens.
Calculation	Number of public transport lines that are equipped with a publicly accessible real-time system to provide people with real-time operation information divided by total number of public transport lines within the city.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 16	**Public transport network covered by a unified payment system**
Description	The indicator assesses the percentage of the city's public transport network covered by a unified payment system. A unified payment system is an integrated mobility payment system that allows transit users to plan, book and pay for multiple modes of transit (such as bus, trams and subways) to get them from point A to point B, thanks to a ICT/technology-based user interface such as smart cards or mobile ticketing, and unified pricing structures.
Calculation	Number of city public transport modes connected by a unified payment system divided by city's total number of public transport modes.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 17	**Smart proximity to public transport**
Description	Population is considered living close to public transport if it is maximum 0,5 km far from the nearest public station that runs frequently (i.e. at least every 20 minutes during peak periods). Peak periods are considered in the morning and in the evening, when traffic volume is highest.
Calculation	It is calculated as the number of inhabitants living within 0,5 km of public transit running at least every 20 min during peak periods divided by total district or city population.
Unit of measure	%
Perimeter of analysis	District
Frequency of reporting	Yearly
Scoring	3
Notes	/

3.6 MOBILITY DATA

KPI n 18	**City commuters using a travel mode to work other than a personal vehicle**
Description	The indicator assesses the percentage of city commuters using a travel mode to work other than a personal vehicle. Non personal vehicle modes include carpools, bus, minibus, train, tram, light rail, ferry, bicycles and walking. In case multiple modes are used, the indicator considers the primary travel mode, by distance travelled using that mode.
Calculation	transportation other than a private vehicle as their primary way to travel to work divided by total number of commuters working in the city. Data can be taken from population surveys.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	Data is mainly gathered from population surveys, therefore the reliability of the measure depends also by the sample of the survey

KPI n 19	**Average commute time**
Description	Commute time for workers is defined as a one-way commute (not round trip) and include only travel from home to place of employment.
Calculation	Average time in minutes that it takes a working person to travel from home to place of employment. Data can be sourced from population surveys or city departments.
Unit of measure	Minutes
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	Data is mainly gathered from population surveys, therefore the reliability of the measure depends also by the sample of the survey

KPI n 20	**Traffic index**
Description	The indicator considers the difference between travel time during peak periods and travel time at free flow periods. The difference between travel time during peak periods and during free flow periods depends also by the distance travelled, for this reason the difference furtherly is divided by the distance travelled. the indicator is a measure of the city congestion.
Calculation	The indicator is defined as the difference between the average travel time for commuters during peak periods and the average travel time for commuters at free flow periods. This difference has to be furtherly divided by total number of kilometers travelled. Data can be sourced from population surveys or local transportation authorities.
Unit of measure	Minutes / km
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	Data is mainly gathered from population surveys, therefore the reliability of the measure depends also by the sample of the survey

3.7 MOBILITY DATA – PRIVATE VEHICLES

KPI n 21	**Number of personal automobiles per capita**
Description	The total number of registered personal automobiles refers to private automobiles used for personal use and does not include automobiles that are used for the delivery of goods and services by commercial enterprises. Automobiles that are electric powered are included.
Calculation	It is calculated as the number of registered personal automobiles in a city at the end of the year divided by total city population.
Unit of measure	#/person
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 22	**Number of two-wheeled motorized vehicles per capita**
Description	Two-wheeled motorized vehicles include scooters and motorcycles, while it does not include non-motorized vehicles such as bicycles.
Calculation	It is calculated as the number of registered two-wheeled motorized vehicles in a city at the end of the year divided by total city population.
Unit of measure	#/person
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

3.8 MOBILITY DATA – GREEN MOBILITY

KPI n 23	**Number of Electric vehicles (EV) registered in the city**
Description	The indicator evaluates the diffusion of electric vehicles in the city. It considers Battery Electric Vehicles (BEV) and Plug-In Hybrid Electric Vehicles (PHEV).
Calculation	It is calculated as the number of registered Electric Vehicles in the city at the end of current year including private, public and service vehicles.
Unit of measure	#
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

KPI n 24	**Percentage of vehicles registered in the city that are low-emission vehicles**
Description	Low-emission vehicles include electric, hybrid and hydrogen-fuel-cell-driven vehicles. Low-emission vehicles shall be certified under appropriate exhaust emission standards and the vehicle shall meet other special requirements applicable to conventional or clean-fuel vehicles and their fuels.
Calculation	Number of registered and approved low-emission vehicles registered in the city at the end of the year divided by total number of vehicles registered in the city at the end of the year. Data can sourced from city departments, or institutions that oversee vehicle registration.
Unit of measure	%
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	4
Notes	/

3.9 MOBILITY DATA – ALTERNATIVE TRANSPORTATION

KPI n 25	**Number of autonomous driving vehicles**
Description	Autonomous driving vehicles refer to vehicles that are self-driving, therefore they do not need for a human driver. Autonomous vehicles could reduce traffic fatalities by eliminating accidents caused by human error.
Calculation	Number of autonomous driving vehicles registered in the city, considering both private vehicles and sharing vehicles. Data can be sourced from city departments or institutions that monitor vehicle registration.
Unit of measure	#
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 26	**Access to car sharing solutions for city travels**
Description	The indicator assesses the availability of car sharing solutions in the city. Car-sharing decreases the need for parking space, less vehicles are on the road and less pollution is emitted.
Calculation	Number of cars available for sharing per 100.000 inhabitants. Data can be sourced from vehicle sharing companies or service providers in the city.
Unit of measure	# per 100 000 inhabitants
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/

KPI n 27	**Number of users of sharing transportation per 100 000 population**
Description	Sharing transportation refers to any transportation modes in which individuals can utilize assets owned by another individual or organization, such as ride-sharing services and automobile-sharing services.
Calculation	Total number of users actively using sharing transportation divided by One 100 000th of the city’s total population. Data can be sourced from dedicated city departments or from sharing transportation service organizations.
Unit of measure	# per 100 000 inhabitants
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	It might be challenging for cities to have access to the required data because of the contrasts in many countries between municipal authorities and sharing transportation providers.

3.10 MOBILITY DATA – ROAD SAFETY

KPI n 28	**Traffic accidents per 100 000 population**
Description	This indicator considers accidents due to any mode of transportation (automobile, public transport, walking, bicycling, etc.) within city limits.
Calculation	It is calculated as the number of transportation accidents of any kind in 1 year divided by one 100 000th of the city's total population.
Unit of measure	# per 100 000 inhabitants
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

KPI n 29	**Transportation deaths per 100 000 population**
Description	This indicator considers deaths due to any mode of transportation (automobile, public transport, walking, bicycling, etc.) within city limits, even if death does not occur at the site of the incident, but is directly attributable to the accident.
Calculation	It is calculated as the number of fatalities related to transportation of any kind in 1 year divided by one 100 000th of the city's total population.
Unit of measure	# per 100 000 inhabitants
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	2
Notes	/

3.11 MOBILITY DATA – PUBLIC TRANSPORTATION

KPI n 30	**Public transport use**
Description	Transport trips include trips via heavy rail metro or subway, commuter rail, light rail streetcars and tramways, organized bus, trolleybus, and other public transport services.
Calculation	Total annual number of transport trips originating in the city divided by total city population. Cities calculate only the number of transport trips with origins in the city itself. Data can be sourced from official transport surveys, revenue collection systems (e.g. number of fares purchased), and national censuses.
Unit of measure	# of trips / person
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	5
Notes	/

KPI n 31	**Average age of public transport fleet**
Description	The indicator is a measure of the grade of innovation of the public transportation system. Newest solutions should guarantee more energy efficient performances.
Calculation	It is calculated as the average age of all the public transportation modes (buses, metro, trains, trams) that serve the city at current year.
Unit of measure	Years
Perimeter of analysis	City
Frequency of reporting	Yearly
Scoring	3
Notes	/