DEVELOPING A WEB-BASED PLATFORM TO VISUALIZE AND ASSESS THE ACHIEVEMENT OF MULTIPLE SDG TARGETS AT THE NEIGHBORHOOD SCALE THROUGH GEOREFERENCED INDICATORS

masters thesis
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Developing a web-based platform to visualize and assess the achievement of multiple SDG targets at the neighbourhood scale through georeferenced indicators

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0_PREFACE

0.1 Glossary

- **2030 Agenda for Sustainable Development (2030 Agenda)**: Formally titled "Transforming Our World: The 2030 Agenda for Sustainable Development," this ambitious agenda was unanimously endorsed by all 193 UN Member States on September 25, 2015, taking effect on January 1, 2016. It aims to promote equitable economic growth, social development, and environmental protection in an integrated and sustainable manner by 2030, encompassing 17 Sustainable Development Goals (SDGs), 169 specific targets, and 231 measurable indicators.
- **5P's**: The five interconnected and mutually reinforcing dimensions around which the 2030 Agenda is structured: **People**, **Planet**, **Prosperity**, **Peace**, and **Partnership**.
    - **People**: Focuses on ending poverty in all forms, combating inequalities, promoting human rights, and achieving gender equality and women's empowerment.
    - **Planet**: Emphasizes protecting and sustainably managing Earth's natural resources, advancing climate-sensitive development that respects biodiversity and builds resilience.
    - **Prosperity**: Aims to create sustained, inclusive, and sustainable economic growth, shared prosperity, and decent work for all, while decoupling economic development from environmental degradation.
    - **Peace**: Commits to building peaceful, just, and inclusive societies, ensuring justice access and strengthening accountable institutions at all levels.
    - **Partnership**: Recognizes that achieving the SDGs requires revitalized global partnerships and collaboration among governments, international organizations, civil society, the private sector, academia, and other stakeholders.
- **Albedo of external surfaces**: An indicator that measures the ability of surfaces to reflect solar radiation to reduce the urban heat island effect.
- **ArcGIS Pro**: A prominent Geographic Information System (GIS) software developed by Esri, widely recognized as an industry standard for geospatial analyses and data management, facilitating detailed spatial data processing and integration.
- **CESBAMED Generic Framework**: A system designed for assessing urban sustainability performance at neighborhood and building scales, used as an initial comprehensive list of indicators for selection.
- **Choropleth map**: A type of thematic map that uses colors or shades to represent statistical data for defined geographic areas, such as Metabolic Units, to visualize distribution patterns and identify hotspots.
- **Dashboard (Web-based Dashboard)**: A common application of digital platforms that consolidates urban information into a single view, providing access to data visualizations that reflect a city's performance against selected indicators. These tools often feature interactive elements and aim for clear, interpretable information display.
- **Demand-centric evaluation methodology**: An approach that shifts the analytical focus from merely counting services or amenities to assessing how effectively each "Metabolic Unit" (or other spatial unit) is served, thereby providing more accurate and contextually relevant insights into neighborhood conditions.
- **Digital Platforms**: Virtual environments that leverage advanced technologies to facilitate sustainable urban development and enhance understanding of urban

dynamics. They are data-centered socio-technical assemblages, crucial components of smart city initiatives.

- **European Handbook for SDG Voluntary Local Reviews**: A methodology designed to guide European local and regional governments in monitoring their progress towards the Sustainable Development Goals (SDGs).
- **Geographic Information Systems (GIS)**: Pivotal tools for urban data visualization and assessment, enabling the integration of large and diverse datasets, creation of spatial models, and detailed analysis with high realism and detail.
- **Georeferenced Indicators**: Quantifiable measures inherently linked to specific geographic locations, offering insights into the state and performance of urban systems over time. They are indispensable for evaluation, measurement, and reporting within urban sustainability decision-making processes.
- **Isochrone**: A geographic area reachable within a specified time limit (e.g., 6 or 10 minutes) by a particular mode of travel (e.g., foot-walking) from a given point. These are used in accessibility analysis to define “liveable areas”.
- **Key Performance Indicators (KPIs)**: Measurable metrics used to systematically evaluate urban sustainability performance and progress toward objectives. For the Turin dashboard, nine key indicators were chosen.
- **Leaving No One Behind (LNOB)**: A central pledge of the 2030 Agenda, emphasizing that no goal should be deemed achieved unless it is met for everyone, with particular attention paid to the poorest and most vulnerable populations.
- **Localization of SDGs**: The process of adapting global SDG objectives to specific local contexts, developing relevant strategies, and engaging various stakeholders throughout planning, implementation, and monitoring processes at the sub-national level.
- **Metabolic Unit (M.U.)**: Basic spatial units of analysis in the case study, defined by aggregated census sections. This demand-centric approach assesses how effectively each M.U. is served by infrastructure and services, providing contextually relevant insights into neighborhood conditions.
- **Neighbourhood Scale**: A strategic middle ground for implementing and monitoring SDG interventions, recognized for being intimate enough to engage citizens and reflect local contexts, yet substantial enough to deliver measurable impacts and inform wider urban strategies.
- **NDVI (Normalized Difference Vegetation Index)**: An indicator calculated from satellite images that verifies the quality of permeable areas and describes the vigor level of greenery, reflecting the environmental health of urban environments.
- **Open-Data**: Initiatives aimed at making public datasets readily available, enhancing transparency, and encouraging broader participation and innovation in urban development.
- **OpenStreetMap (OSM)**: A free, editable map of the world, serving as a topographic base layer for data visualization in choropleth maps and providing data for routing services.
- **PM10/PM2.5**: Particulate Matter concentrations (PM10 and PM2.5) are indicators used to measure air quality by quantifying the number of people exposed to high concentrations of these pollutants.
- **QGIS (ORS Tools Plugin for QGIS)**: An open-source Geographic Information System (GIS) software. The ORS Tools Plugin connects to OpenRouteService via an API, using OpenStreetMap data to create isochrone polygons for accessibility analysis.

- **Regio Parco**: A district located northeast of Turin's city center, chosen as the case study area for the web-based dashboard prototype due to its heterogeneous characteristics, green spaces, ongoing urban regeneration, cultural hubs, and strategic location.
- **SNTool (Sustainable Neighborhood Tool)**: An Excel-based system used for evaluating urban neighborhood sustainability performance, which integrates a multi-criteria analysis into a hierarchical assessment structure.
- **Spatial Decision Support Systems (SDSS)**: Digital platforms that assist decision-makers in sustainable urban planning through interactive dashboards, enabling scenario development and KPI assessment using GIS tools and georeferenced data.
- **Sustainable Development**: A holistic concept, first introduced in the 1987 Brundtland Report, defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". It considers environmental, economic, and social dimensions for long-term sustainability.
- **Sustainable Development Goals (SDGs)**: The 17 goals outlined in the 2030 Agenda for Sustainable Development, serving as a comprehensive framework to promote equitable economic growth, social development, and environmental protection universally. They are supported by 169 targets and over 230 unique indicators.
- **Urban Metabolism (UM) Theory**: A conceptual framework that views cities as organisms with flows of resources and waste, used to analyze urban systems and develop meaningful indicators at various spatial scales.
- **Urban Sustainability**: A framework introduced in the 1992 Rio Declaration that guides urban planning and decision-making by focusing on the capacity of cities to implement actions and technologies that support ongoing development while preserving natural, social, and economic resources and minimizing adverse impacts.
- **Voluntary Local Reviews (VLRs)**: Mechanisms through which local governments assess and report progress towards national and global SDG commitments, aligning municipal actions with broader sustainability agendas.

0.2 Abstract

The global imperative for sustainable development, encapsulated by the **United Nations 2030 Agenda and its 17 Sustainable Development Goals (SDGs)**, highlights an urgent need for effective local action. Cities, recognized as central to both generating and resolving global challenges, are critical to achieving these goals; however, translating broad global objectives into actionable local strategies remains a significant hurdle. Top-down approaches frequently overlook the nuanced spatial dynamics and socio-economic disparities at the micro-level, emphasizing the need for granular monitoring. This master's thesis addresses this gap by focusing on the **neighbourhood scale** as a strategic middle ground—intimate enough to engage citizens and reflect local contexts, yet substantial enough to inform wider urban strategies and foster participatory planning.

This research introduces the development of a **web-based dashboard prototype** specifically designed for visualizing and assessing SDG indicators at the neighbourhood level, using Turin, Italy, as a case study in the Regio Parco district. The methodology integrates a robust, **multidisciplinary GIS-based framework** and a participatory, multi-criteria approach for indicator selection. Leveraging ArcGIS Pro and QGIS, the prototype systematically processes and integrates diverse georeferenced data through the calculation of its indicators and aims to include, in a future, **eight key indicators,** spanning accessibility to basic services, green areas, and public transport, alongside per capita energy consumption, waste production, air quality, green quality, and tree cover for microclimate management. A core contribution is its **demand-centric evaluation methodology**, which shifts the analytical focus from merely counting services to assessing how effectively each "Metabolic Unit" (defined by aggregated census sections) is served, thereby providing more accurate and contextually relevant insights into neighbourhood conditions.

The dashboard prototype significantly advances urban planning by translating abstract global goals into practical, locally tailored strategies, supporting **evidence-based decision-making and transparent governance**. Its user-centered design and interactive visualizations facilitate participative processes, fostering broader stakeholder engagement and collaborative planning essential for resilient urban transformations. The flexible methodological framework enhances its adaptability and replicability across diverse urban settings, enabling comparative analysis and benchmarking. Future research should prioritize the **integration of real-time data**, optimization of planning processes for **inclusive accessibility**, addressing **data limitations and methodological inconsistencies**, **standardization of neighbourhood definitions**, and **enhanced participatory governance** to strengthen local ownership and bridge policy-community divides. This prototype lays a foundational step towards more nuanced, data-driven, and inclusive urban planning for truly sustainable and equitable cities.

0.3 Introduction

The urgency of addressing global challenges related to sustainable development has brought the **2030 Agenda for Sustainable Development** and its **Sustainable Development Goals (SDGs)** to the forefront of international policy. First introduced by the 1987 Brundtland Report, the concept of sustainable development is defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs," emphasizing a holistic balance of environmental, economic, and social dimensions. Cities are identified as central to both generating and resolving these global challenges, being largely responsible for urgent contemporary issues. Consequently, **urban sustainability**, a framework introduced in the 1992 Rio Declaration, has become crucial for guiding urban planning and decision-making processes, aiming to implement actions and technologies that support ongoing development while preserving natural, social, and economic resources and minimizing adverse impacts. The 2030 Agenda, unanimously endorsed by all 193 UN Member States in 2015, delineates 17 SDGs, 169 specific targets, and 231 measurable indicators, representing a comprehensive framework designed to promote equitable economic growth, social development, and environmental protection universally across both developed and developing nations.

While global frameworks provide necessary guidance, **effective sustainability monitoring necessitates a focus on the local and, more specifically, the neighbourhood scale**. Cities, which currently house the majority of the world's population and generate over 75% of global GDP, also consume more than 70% of resources and produce similar percentages of greenhouse gas emissions and waste, positioning them as critical hubs for both problems and solutions. It is estimated that over 65% of SDG targets rely on contributions at the urban level, making the **localization of SDGs**—adapting global objectives to specific local contexts—fundamental for success. The neighbourhood emerges as a strategic scale for implementation, offering a distinct spatial-social context that facilitates detailed analysis and practical relevance. This scale is intimate enough to engage citizens and reflect local contexts, yet substantial enough to deliver measurable impacts and inform wider urban strategies. At the neighbourhood level, residents directly experience the impact of urban policies, making these areas ideal for evaluating planning decisions and fostering participatory governance. However, applying the SDG framework at this granular level faces critical challenges, including the insufficient availability and fragmentation of high-quality data, methodological inconsistencies, the lack of standardized "neighbourhood" definitions, and limited local governance capacity.

In response to these challenges, **digital platforms and georeferenced indicators have emerged as pivotal tools for enhancing urban sustainability efforts**. Digital platforms are virtual environments that leverage advanced technologies to facilitate sustainable urban development, enabling the comprehensive collection, processing, and display of heterogeneous urban data. Key features of these platforms include interactive and real-time capabilities, robust data aggregation and analysis, integration of diverse data sources (e.g., IoT devices, sensors, remote sensing), multi-scale spatial capabilities, and features promoting participatory governance and openness. **Georeferenced indicators**, quantifiable measures intrinsically linked to specific geographic locations, are indispensable for evaluation, measurement, and reporting within decision-making processes for urban sustainability. Geographic Information Systems (GIS) are central to this process, enabling the integration of large datasets and the creation of spatial models that facilitate clear visualization and identification of patterns, trends, and anomalies at various scales, from city-wide to the granular neighbourhood level. Examples such as Eindhoven in Cijfers, DATA2GO.NYC, and the Spatial Decision Support System (SDSS) for Turin demonstrate the power of such tools in monitoring urban performance, enhancing civic engagement, and supporting evidence-based policy formulation.

This thesis presents the methodology for the **development of a web-based dashboard prototype specifically designed to visualize and assess Sustainable Development Goal (SDG) indicators at the neighbourhood scale**, thereby addressing a critical gap in localizing global sustainability objectives. A core contribution is the establishment of a **demand-centric evaluation methodology** for indicators, which shifts the analytical focus from merely counting services to assessing how effectively each “Metabolic Unit” (M.U.)—defined by aggregated census sections—is served. This approach provides more accurate and contextually relevant insights into neighbourhood conditions.

0.4 Research methodology

The research methodology for this study can be understood by distinguishing between its explicit research questions and the implied methodological approaches derived from the provided sources.

0.4.1 Research Questions

The central focus of the research is encapsulated in its **Main Research Question**:

- **How can a web-based platform be developed to visualize and assess the achievement of multiple SDG targets at the neighbourhood scale through georeferenced indicators?**
    - This question is also presented as the subject of the thesis and the overall research question. The aim of the research is to achieve SDG targets at the neighbourhood scale with the creation of a web platform that collects and displays georeferenced sustainability indicators.

To address this main question, several **Sub-questions** are outlined, categorized to guide the research process:

- **State of the Art Questions**:
    - Current research and academic literature on achieving multiple SDG targets at the neighbourhood scale using georeferenced indicators.
    - Methodologies for developing web-based platforms for visualizing and assessing SDG target achievement at the neighbourhood level.
- **Literature Review Questions**:
    - How existing web platforms are used at the neighbourhood and urban scales to support SDGs or urban sustainability.
    - The spatial scale at which digital platforms for SDG-related purposes or urban sustainability are developed.
    - Types of studies, projects, or initiatives addressing SDG implementation at the neighbourhood, urban, or micro-urban scales.
    - Main research gaps identified in review papers or meta-analyses concerning SDG monitoring and georeferenced data visualization through digital platforms.
- **Validity of the Model and Disciplinary Approaches Questions**:
    - The continued validity of the **SDG framework** for urban sustainability, including critiques and recent updates in urban contexts.
    - How SDGs are adapted or applied to the micro-urban/neighbourhood scale.
    - How different disciplines (urban planning, engineering, social sciences, data science) approach SDG implementation and monitoring at the neighbourhood scale.
- **Existing Tools and Datasets Questions**:
    - Identification of existing digital platforms that perform visualization and assessment of multiple SDG targets at the neighbourhood or urban scale through **georeferenced indicators**.

        - If existing platforms are found, their features, methodologies, and data types will be examined.
    - Investigation of digital platforms supporting **smart city initiatives** that perform visualization and assessment of SDG targets at the neighbourhood scale using open-data-driven local systems.
    - Current availability and quality of urban data, particularly at the **neighbourhood level**, including insights from academic literature on accessibility, granularity, and reliability.
- **Case Studies Questions**:
    - The possibility of designing a method or platform that is **scalable or adaptable** across different contexts or scales for SDG visualization and assessment.
    - Examples from literature or projects of scalable or transferable solutions.

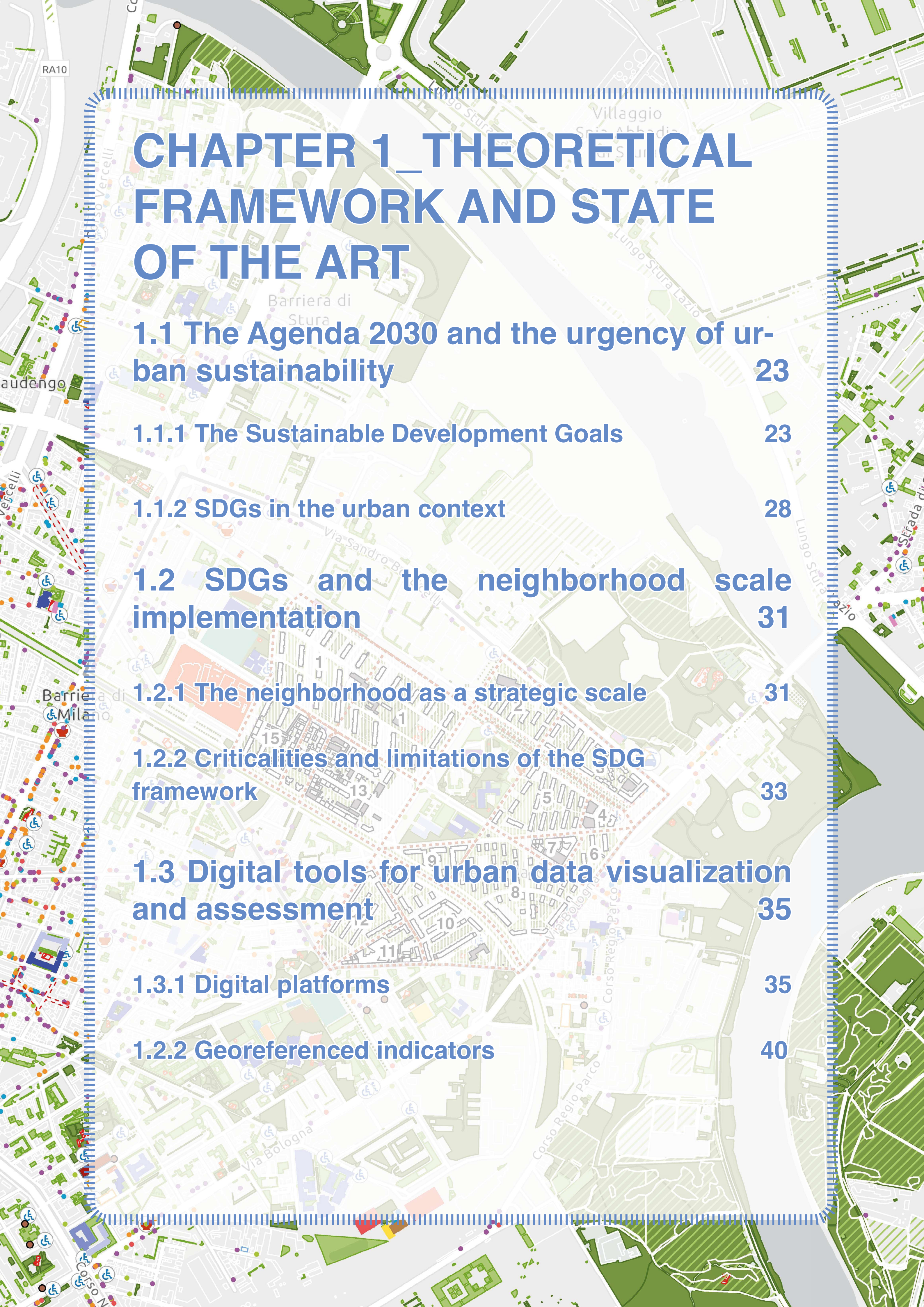
0.4.2 Methodology

The research methodology involves a multi-faceted approach scoping review, focusing on **literature review**, **platform development**, and **data utilization** at a specific **spatial scale**:

1. **Literature Review and State-of-the-Art Analysis**:
    - A **systematic review** approach is indicated by the extensive list of “PRIMARY RESEARCH STRING KEYWORD COMBINATION OF SYNONIMS”. These strings are designed to identify relevant academic literature and research.
    - **Keywords and Synonyms** used in the search strings cover core concepts such as:
        - **Action/Assessment**: “ASSESS*”, “ACHIEV*”, “EVALUATION”, “MONITORING”, “TRACKING”, “MEASUREMENT”.
        - **Sustainability Frameworks**: “SUSTAINABLE DEVELOPMENT GOAL*”, “SDGs”, “SDG TARGET*”, “SDG INDICATOR*”, “SDG11”, “SUSTAINABLE DEVELOPMENT”, “SUSTAINABILITY”, “SUSTAINABLE URBAN PLANNING”, “SUSTAINABLE DEVELOPMENT MEASURE”.
        - **Geospatial Tools**: “GEOGRAPHIC INFORMATION SYSTEM*”, “GIS”, “SPATIAL ANALYSIS”, “GEOINFORMATION”, “MAPPING”, “GEOSPATIAL DATA”, “REMOTE SENSING”, “GIS INTEGRATION”.
        - **Indicators/Metrics**: “INDICATOR*”, “METRIC*”, “MEASURE*”, “COMPOSITE INDICATOR*”, “MULTI CRITERIA DECISION MAKING”, “DECISION MAKING”, “URBAN METABOLISM*”, “ASSESSMENT METHODOLOG*”.
        - **Scales**: “URBAN SCALE”, “CITY SCALE”, “MUNICIPAL SCALE”, “NEIGHBO?RHOOD SCALE”, “LOCAL LEVEL”, “COMMUNITY LEVEL”, “CITY DISTRICT”, “CITY-SCALE”, “COMMUNITY SCALE”.
        - **Digital Urbanism Concepts**: “SMART CITY”, “DIGITAL TWIN”, “INTERNET OF THINGS”, “IOT”, “DATA-DRIVEN URBANISM”.
        - **Platform/Visualization**: “WEB-BASED PLATFORM”, “DATA VISUALIZATION”, “GIS-BASED TOOL*”, “INTERACTIVE DASHBOARD*”, “SMART CITY PLATFORM*”, “VISUALIZATION”,

"INTERACTIVE MAPS", "INFORMATION SYSTEM*".

In summary, the research outlines a plan to develop a practical **web-based platform** to aid in **SDG monitoring at the neighbourhood level** using **geospatial data**, grounded in a thorough **systematic literature review** to understand existing methodologies, identify gaps, and evaluate current tools and data availability. The study's aim is to contribute to localized sustainability by creating a tool for visualizing and assessing progress.



CHAPTER 1_THEORETICAL FRAMEWORK AND STATE OF THE ART

1.1 The Agenda 2030 and the urgency of urban sustainability

1.1.1 The Sustainable Development Goals

The design of the “Sustainable Development Goals” (SDGs) follows the origin of the concept of sustainable development, which was first introduced in the 1987 Brundtland Report by the World Commission on Environment and Development (WCED). This is a holistic concept defined as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

It has become the organizing principle guiding global efforts toward balancing human development with environmental care (WCED, 2025). The core idea on which sustainable development is based is to consider environmental (bio-physical), economic, and social dimensions to ensure long-term sustainability and a harmonious coexistence between human activities and the natural environment (Bibri, S.E., 2021; Khodakarami et al., 2023; Costa et al., 2024), rather than solely aiming at the achievement of human development goals. Sustainable development, in addition, involves the concept of sustaining natural systems that provide essential resources and ecosystem services on which economies and societies depend. However, after more than four decades, environmental degradation due to resource over-exploitation and pollution continues to threaten sustainable development worldwide (Das et al., 2023).

Cities are pivotal in both generating and solving global challenges related to sustainable development; in fact, they could be identified as mainly accountable for the most urgent contemporary challenges (Pignatelli et al., 2023). In the urban environment context, to that end, sustainability includes the capacity of cities to implement actions and technologies to support ongoing development while preserving natural, social, and economic resources, thereby minimizing adverse impacts (Costa et al., 2024).

The concept of urban sustainability was introduced in the 1992 Rio Declaration on Environment and Development, and since then, it has become a crucial framework for guiding urban planning and decision-making processes. Achieving sustainable urban development, however, involves addressing the so-called “wicked problems”, which are the complex and multidimensional challenges, typical of the Anthropocene epoch, characterized by multiple stakeholders, intricate interdependencies, and unpredictable outcomes (Bibri et al., 2024). Urban sustainability assessment tools, as a result, have been developed to monitor progress toward sustainability goals and support effective policy and planning (Khodakarami et al., 2023).

Following an extensive two-year consultation process involving civil society organizations, scientific communities, academic institutions, and global citizens, the 2030 Agenda for Sustainable Development, formally titled *“Transforming Our World: The 2030 Agenda for Sustainable Development,”* was unanimously endorsed by all 193 UN Member States ofthe United Nations General Assembly on September 25, 2015, and took effect on January 1, 2016 (Trane et al., 2023; UN, 2015; Gong, 2019; WCED, 2025, n.d.; Lorenzo-Sáez et al., 2021; Patole, 2018).

This ambitious agenda aims to promote equitable economic growth, social development, and environmental protection in an integrated and sustainable manner by 2030, encompassing the delineation of 17 Sustainable Development Goals (SDGs) (Ahmed et al., 2024; Gervasi et al., 2024).

The 2030 Agenda represents a comprehensive framework structured around the “5P’s”: People, Planet, Prosperity, Peace, and Partnership. It delineates, other than the SDGs, 169 specific targets and 231 measurable indicators that systematically integrate environmental, social, and economic considerations into a unified strategic approach (Gervasi et al., 2024; Das et al., 2023).

The SDGs represent a significant evolution from their predecessors, the Millennium Development Goals (MDGs), which expired in 2015. This comprehensive framework was developed in response to recognized limitations of the MDGs, which, while successful in raising awareness and establishing political priorities, were hampered by insufficient localization efforts, inadequate local implementation capacity, and suboptimal data management systems, which collectively impeded effective execution at sub-national levels (Ekmen & Kocaman, 2024; Patole, 2018).

While the MDGs focused primarily on poverty reduction in developing countries, the SDGs expand the framework to address a broader spectrum of economic, social, and environmental challenges. This more comprehensive approach applies universally to both developed and developing nations (Patole, 2018; Biermann et al., 2017). The Agenda 2030 aims to confront critical global issues, including inequality, poverty, and climate change impacts. It identifies poverty eradication in all manifestations—particularly extreme poverty—as the foremost global challenge and an essential condition for sustainable development (Das et al., 2022; United Nations General Assembly, 2015).

Implementing the SDGs by 2030 demands coordinated action across all governance levels, from global to local. Though not legally binding, governments are expected to establish national frameworks to implement these goals. The 2030 Agenda emphasizes monitoring and reporting progress as essential components that help identify policy gaps and assess effectiveness. The United Nations High-Level Political Forum (HLPF) functions as the central platform for global follow-up and review (Patole, 2018).

The broader context necessitating the Agenda 2030 is framed by the complex and interconnected global challenges characteristic of the Anthropocene epoch. Within its theoretical framework, consequently, the 2030 Agenda for Sustainable Development establishes fundamental principles that reflect a global commitment based on key tenets essential for its successful worldwide implementation.

Universality

The 2030 Agenda and its Sustainable Development Goals (SDGs) apply universally to all countries, regardless of development status. This universality acknowledges that global challenges like poverty, hunger, and climate change demand coordinated action from all nations, both developed and developing (United Nations General Assembly, 2015; WCED, 2025.pdf). The Agenda was adopted following extensive public consultation and engagement with diverse stakeholders, including civil society and marginalized populations, ensuring that the voices of the poorest and most vulnerable shaped the goal-setting process (United Nations General Assembly, 2015).

Integration and Indivisibility

The SDGs constitute an integrated and indivisible set of objectives that balance the economic, social, and environmental dimensions of sustainable development (United Nations General Assembly, 2015). Achieving these goals inclusively requires robust indicators and analytical tools for measuring, monitoring, and communicating progress across multiple scales—from local to global (Fukui et al., 2021). However, challenges persist in fully operationalizing this integration, particularly in accounting for the complex interlinkages and potential conflicts within the SDGs framework (Trane et al., 2023). Harnessing synergies while minimizing adverse trade-offs is critical, as failures in one area can trigger cascading negative impacts across other goals (Trane et al., 2023).

The Five Ps (5Ps)

The Agenda is structured around five interconnected and mutually reinforcing dimensions—known as the “5Ps”: People, Planet, Prosperity, Peace, and Partnership (Gervasi et al., 2024).

- **People** focuses on ending poverty in all forms, combating inequalities, promoting human rights, and achieving gender equality and women’s empowerment (United Nations General Assembly, 2015).
- **Planet** emphasizes protecting and sustainably managing Earth’s natural resources, advancing climate-sensitive development that respects biodiversity and builds resilience (United Nations General Assembly, 2015). For example, SDG 11 on sustainable cities and communities directly contributes to environmental sustainability, climate action, and ecosystem conservation through green urban spaces that provide vital ecosystem services (Lorenzo-Sáez et al., 2021).
- **Prosperity** aims to create sustained, inclusive, and sustainable economic growth, shared prosperity, and decent work for all, while decoupling economic development from environmental degradation (United Nations General Assembly, 2015).
- **Peace** commits to building peaceful, just, and inclusive societies, ensuring justice access and strengthening accountable institutions at all levels (United Nations General Assembly, 2015).
- **Partnership** recognizes that achieving the SDGs requires revitalized global partnerships and collaboration among governments, international organizations, civil society, the private sector, academia, and other stakeholders (United Nations General Assembly, 2015).

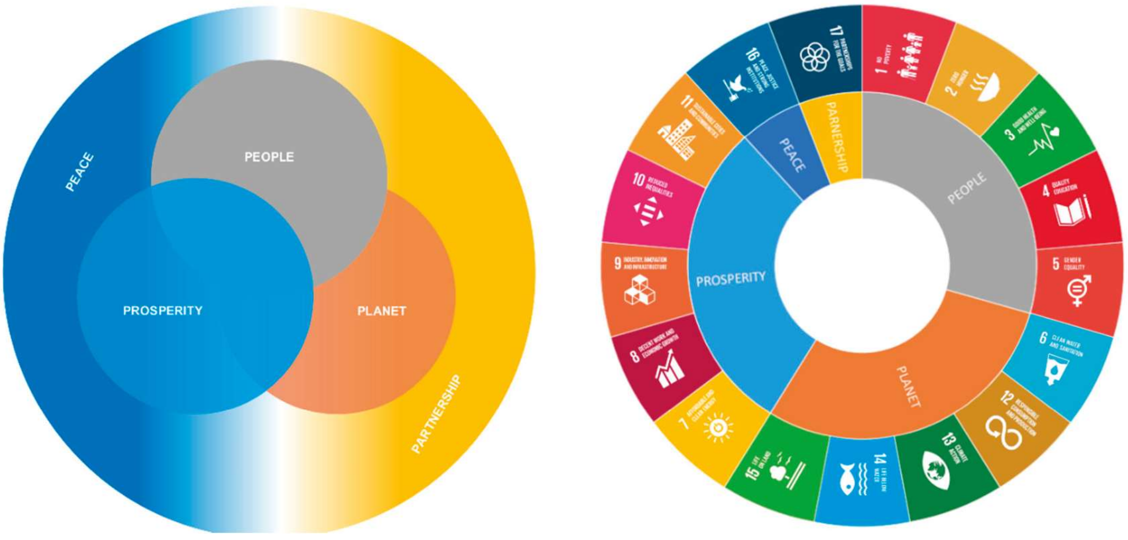


Fig. 1: The United Nations 2030 Agenda categorizes Sustainable Development Goals into five key dimensions: People (Goals 1-5), Planet (Goals 6, 12-15), Prosperity (Goals 7-11), Peace (Goal 16), and Partnership (Goal 17). This framework is known as the 5Ps concept.
source: Ho, L.T. et al., 2019

Leaving No One Behind (LNOB)

Central to the Agenda is the pledge that no goal should be deemed achieved unless it is met for everyone, with particular attention paid to the poorest and most vulnerable populations (Machingura, 2017). This principle underscores the imperative to reduce inequalities within and among countries and ensure equitable access to rights and opportunities (WCED, 2025). Success in this regard depends on the availability of disaggregated, high-quality data that can effectively track progress and identify those who remain marginalized (WCED, 2025).

Multi-level and Multi-stakeholder Engagement

The 2030 Agenda implementation demands coordinated action across all governance levels—from global to local—with active participation from diverse stakeholders, including governments, parliaments, the UN system, local authorities, indigenous peoples, civil society, the private sector, and the scientific community (United Nations General Assembly, 2015). Local governments, particularly cities and communities, are crucial due to their proximity to social, economic, and environmental challenges and their ability to influence sustainable behaviors and choices (Siragusa et al., 2021). Localizing the SDGs involves adapting global objectives to specific local contexts, developing relevant strategies, and engaging various stakeholders throughout planning, implementation, and monitoring processes (Gazzarri, 2023).

Data-Driven Monitoring and Accountability

Scientific research strengthens the SDGs through metric development, monitoring mechanisms, progress evaluation, infrastructure enhancement, and data standardization. Geospatial technologies—particularly remote sensing and Geographic Information Systems (GIS)—have become vital tools for assessing SDG indicators, visualizing regional disparities, and informing future planning (Qwaider et al., 2023). Despite these advances, significant challenges in data quality, availability, and tool utilization persist, especially in developing countries (Patole, 2018).

Robust monitoring, reporting, and accountability systems are fundamental to the Agenda's success. The SDGs incorporate a comprehensive global framework of 169 targets and over 230 unique indicators that measure progress and identify policy gaps (Ahmed et al., 2024; Trane et al., 2023). For informed decision-making and ensuring no one is left behind, high-quality, accessible, timely, and disaggregated data are essential (United Nations General Assembly, 2015). The Agenda recognizes the need to strengthen statistical capacities—particularly in developing countries—and emphasizes the value of innovative data sources such as geospatial information and big data to enhance monitoring capabilities (Avtar et al., 2020).

To evaluate national SDG performance, "The Sustainable Development Goals Index (SDGI)" was developed, measuring performance on a scale from 0 (worst) to 100 (full compliance). Nordic countries and Switzerland consistently lead the index, with Sweden, Denmark, Norway, and Finland at the top. Many African nations rank lowest due to ongoing challenges with poverty, hunger, education, and governance. Major Western nations hold intermediate positions, with the United Kingdom (78.1), Canada (76.8), Australia (74.5), and the United States (72.7) showing varied progress (Das et al., 2022).

Recent UN progress reports indicate that, despite global efforts, none of the 17 SDGs will likely be fully achieved by the 2030 deadline. This underscores the critical urgency of accelerating sustainable development initiatives worldwide (Frantzeskaki et al., 2025).

The 17 SDGs encompass a comprehensive range of objectives organized into interconnected goals covering poverty reduction, health, education, gender equality, clean energy, economic growth, innovation, reduced inequalities, sustainable cities, responsible consumption, climate action, biodiversity conservation, peace, justice, and global partnerships (Mumtaz et al., 2025; Costa et al., 2024). These goals provide a detailed blueprint guiding global efforts toward a sustainable and equitable future.

Each goal is further specified through 169 targets designed to be adapted into national plans and policies based on each country's unique context. Effective implementation depends on understanding the connections among these targets to maximize synergies and minimize trade-offs, enabling coherent and integrated policy responses (Trane et al., 2023).

Indicators

The 2030 Agenda for Sustainable Development established a comprehensive global indicator framework with over 230 unique indicators to measure progress toward its 169 targets (Ahmed et al., 2024).

These indicators function as critical statistical tools for monitoring, reporting, and supporting evidence-based decisions. The 2030 Agenda stresses the importance of accessible, timely, reliable, and disaggregated data to ensure no one is left behind in sustainable development efforts (United Nations, 2015; Alonso Frank & Mattioli, 2023).

High-quality data disaggregated by income, sex, age, ethnicity, disability, and geographic location is essential for accurately assessing progress across global, regional, and national levels (Patole, 2018).

The Inter-Agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs) was established to develop and implement this global indicator framework, providing an objective basis for annual assessments of SDG progress worldwide (Xin et al., 2024). This group categorizes indicators into tiers based on their methodological maturity and data availability, enabling targeted improvements in measurement practices (Patole, 2018).

Scientific rigor forms the foundation for defining indicators and metrics, ensuring they are measurable, comparable, and achievable. The European Commission's Joint Research Centre has developed integrated approaches for monitoring SDGs at the local level, working directly with cities to customize indicators and establish local monitoring ecosystems. This collaboration enables municipalities to effectively conduct Voluntary Local Reviews (Siragusa et al., 2021).

A key challenge in SDG monitoring is localizing the global framework. While global indicators provide a common language, adapting them to national, regional, or urban contexts—where over 80% of the European population resides—requires developing context-specific indicators that reflect local priorities and conditions (Lorenzo-Sáez et al., 2021). Local governments are essential for data collection and organization, frequently using Voluntary Local Reviews to assess and report progress at sub-national levels (Siragusa et al., 2021).

Advanced technologies—including geospatial information systems, remote sensing, big data analytics, artificial intelligence, and citizen science—are increasingly enhancing the monitoring, evaluation, and visualization of SDG indicators. These tools improve multi-stakeholder cooperation, enable integrated data sharing ecosystems, and boost transparency in sustainable development governance (Xin et al., 2024). One example of a tool useful for this objective is the interactive visualization platform, such as web-based dashboards, which have become vital tools for communicating SDG status to policymakers and the public. These systems use thematic maps, interactive charts, and analytical tools to transform complex data into accessible, actionable information, facilitating informed decision-making (Gong, 2019).

At its core, the SDG indicator framework forms a nested structure where broad, universal goals are divided into specific targets, which are then tracked through measurable indicators. This framework promotes integrated action and thorough monitoring across all governance levels to drive sustainable development worldwide (Senger, 2024).

1.1.2 SDGs in the urban context

The importance of the SDG framework extends critically to the local level, where cities and local governments are recognized as key actors in achieving the 2030 Agenda. It is estimated that over 65% of the SDG targets rely on contributions at the urban level, underscoring the crucial role of cities in sustainable development (Ekmen & Kocaman, 2023). This emphasis aligns with SDG 11, which focuses on making cities inclusive, safe, resilient, and sustainable, recognizing urban areas as vital drivers of social, economic, and environmental sustainability (United Nations, 2015).

Urban areas, in fact, currently house the majority of the world's population and are projected to reach nearly 5 billion inhabitants by 2030 (United Nations, 2019). While cities generate more than 75% of global GDP (Frantzeskaki et al., 2025), they also consume over 70% of resources, produce a similar percentage of GHG emissions and waste, despite occupying less than 10% of the Earth's surface (IEA, 2021). This dual nature places cities at the heart of both sustainability challenges and solutions.

With their detailed territorial knowledge, local governments are ideally positioned to customize strategies for specific urban needs. Furthermore, approximately one-third of SDG indicators can be monitored locally (Lorenzo-Sáez et al., 2021).

Cities function as real-world laboratories for testing and scaling innovative sustainability solutions, ranging from climate adaptation strategies to circular economy initiatives (Frantzeskaki et al., 2025). They provide an essential framework upon which global efforts for climate resilience and sustainable development must be built (Melica et al., 2018).

Despite their strategic role, cities face significant challenges in implementing the SDGs effectively. A primary difficulty is translating global targets into actionable, measurable objectives at the local level. While the SDGs provide a universal roadmap, they weren't originally designed with urban specificity in mind, creating a gap between global ambition and local applicability (Acuto et al. 2018).

The SDGs aim to provide a flexible framework that enables the adaptation of global goals to the specific realities of local contexts, accommodating diverse needs, challenges, and priorities. Localization involves integrating the SDGs into municipal policy frameworks across social, economic, and environmental dimensions, prioritizing goals and indicators that enable monitoring and reorientation of local government actions (United Nations, 2020c; Alonso Frank & Mattioli, 2023). This process is fundamental, as no goal should be considered achieved unless it is fulfilled for everyone, emphasizing equity and inclusivity at the local level (Melamed, 2015).

The localization process provides a more granular understanding of sustainability by identifying spatial and social disparities and prioritizing areas for improvement. Data and metadata disaggregation is crucial in this process, enabling targeted interventions that address sub-national realities (Patole, 2018).

The SDG framework, indeed, with its indicators and disaggregated data, offers a vital evidence base for strategic planning and policy development at the local level. Local governments serve as key monitors of progress through mechanisms such as Voluntary Local Reviews (VLRs), which align municipal actions with national and global SDG commitments (Alonso Frank & Mattioli, 2023; Siragusa et al., 2021).

Tackling complex urban challenges—energy, water, waste management, transport, air quality, biodiversity, housing, and public health—demands integrated planning approaches grounded in the SDG framework (OECD, 2020). Urban sustainability assessment spans economic, social, and environmental domains and benefits from innovative, participatory methods that strengthen local ownership and effectiveness (Brandon, Lombardi, & Shen, 2024; European Commission, 2021).

The framework promotes engagement of diverse local stakeholders—communities, academia, and governmental bodies—in participatory processes to establish priorities, co-create strategies, and enable effective monitoring. These collaborative approaches are crucial for building local legitimacy and ensuring SDG implementation reflects urban populations' values and needs (Trane et al., 2023).

Data availability and quality are critical enablers of SDG localization. Traditional data sources often prove inadequate, particularly in developing countries where data gaps and quality issues impede comprehensive monitoring. Geospatial technologies, including Geographic Information Systems (GIS) and remote sensing, have become essential tools for collecting, analyzing, visualizing, and monitoring SDG indicators from global to neighborhood scales (Avtar et al., 2020).

These technologies deliver synoptic views, facilitate consistent cross-geographical comparisons, provide detailed granularity, and effectively communicate the geographic dimensions of sustainable development challenges and progress. Integrating earth observation data, in-situ sensors, and advanced spatial analysis techniques supports robust monitoring systems adaptable to diverse contexts (Avtar et al., 2020; Gong, 2019).

In summary, SDG localization is a dynamic process that transforms global ambitions into concrete actions tailored to local realities. It depends on adaptive governance, inclusive stakeholder engagement, quality disaggregated data, and innovative technologies to ensure truly inclusive sustainable development.

This gap is worsened by fragmented governance and data systems. Many cities lack the institutional capacity or resources to collect, process, and monitor reliable SDG-aligned indicators (Melica et al., 2018). Even when data exists, inconsistencies in definitions, scales, and methodologies hinder comparability and long-term planning (Siragusa et al., 2020).

Additionally, integrating sustainability into urban policy requires navigating overlapping agendas—climate action, social equity, and digital transformation—that often compete for resources or are addressed in isolation rather than systemically (Bibri et al., 2024). Consequently, implementation tends to be reactive, fragmented, or symbolic, lacking the coherence needed for meaningful transformation (Frantzeskaki et al., 2025).

However, these challenges create opportunities for innovation. Cities are increasingly adopting localized frameworks and participatory governance models to align planning with SDG principles (Lorenzo-Sáez et al., 2021). Urban experimentation—through pilot projects, partnerships, and digital platforms—is emerging as a powerful approach to contextualize and test global goals locally (Pignatelli et al., 2023).

In sum, while structural constraints persist, urban contexts offer both urgency and opportunity to reframe sustainability from the ground up.

In this complex urban landscape, a key challenge is ensuring sustainability efforts align with global goals while responding to urban communities' lived realities. As cities expand, top-down approaches often fail to address the diverse local needs, spatial dynamics, and socio-economic inequalities that influence sustainability outcomes at the micro level (Pignatelli et al., 2023).

This challenge has sparked interest in identifying the optimal spatial scale for implementing and monitoring SDG interventions. While national and city-wide policies provide necessary guidance, they frequently lack the granularity needed for meaningful community-level change. The neighbourhood scale emerges as an effective middle ground: intimate enough to engage citizens and reflect local contexts, yet substantial enough to deliver measurable impacts and inform wider urban strategies.

Neighbourhoods are now recognized beyond mere spatial units to serve as hubs for participatory planning, cross-sector collaboration, and innovation. By strengthening connections between residents, decision-makers, and data, neighbourhood initiatives can translate sustainability principles into inclusive, context-appropriate actions (Frantzeskaki et al., 2016).

The following section examines the rationale for focusing on the neighbourhood scale in SDG implementation, exploring its strategic advantages, methodological challenges, and potential to bridge the gap between global frameworks and local realities.

Fig. 2: Sustainable Development Goals
source: https://www.un.org/sustainabledevelopment/news/communications-material/

1.2 SDGs and the neighborhood scale implementation

1.2.1 The neighborhood as a strategic scale

Research increasingly acknowledges the neighbourhood as a strategic implementation scale for Sustainable Development Goals (SDGs), as noted in academic literature and planning practice. Situated between municipal and household levels, neighbourhoods offer a distinct spatial-social context that facilitates both detailed analysis and practical relevance when addressing sustainability challenges.

Neighbourhoods function as essential environments where sustainability manifests in everyday life. These spaces concentrate social interactions and reveal tangible issues related to equity, access, and quality of life (Alsherfawi Aljazaerly et al., 2024). This direct connection to residents' experiences makes neighbourhoods particularly valuable for examining how spatial and social dynamics affect sustainability outcomes.

The adaptation of global sustainability objectives to the neighbourhood context enhances implementation effectiveness. While SDG frameworks maintain universal applicability, successful execution necessitates approaches tailored to specific conditions. Neighbourhood-scale initiatives facilitate the customization of global objectives to local circumstances, encouraging community engagement and enabling grassroots action that larger-scale approaches typically find challenging (Saiu et al., 2024; Alonso Frank & Mattioli, 2023).

Residents experience the impact of urban policies most directly at the neighbourhood level, establishing this scale as a crucial interface for evaluating the practical effects of planning decisions and sustainability measures (Trane et al., 2023). From transportation infrastructure to public space design and service accessibility, neighbourhood-focused interventions produce measurable results and provide valuable feedback for broader planning initiatives.

From an analytical perspective, neighbourhoods provide a level of detail that city-wide approaches cannot match. Assessments conducted at the neighbourhood level yield comprehensive insights into socio-environmental conditions, enabling urban planners to identify specific areas requiring targeted interventions and resource allocation (Khodakarami et al., 2023). This detailed approach supports more effective planning while avoiding the oversimplifications often associated with aggregated urban data.

Additionally, this scale facilitates participatory governance and enhances local ownership of initiatives. Engaging diverse stakeholders—including residents, local institutions, non-governmental organizations, and planners—at the neighbourhood level fosters collaboration, builds trust, and establishes long-term commitment to shared sustainability objectives (Alonso Frank & Mattioli, 2023). This creates opportunities for collaborative development, testing, and refinement of interventions essential for resilient and inclusive urban transformation.

Various theoretical frameworks and planning instruments underscore the significance of neighbourhood-scale planning. For instance, Neighbourhood Sustainability Assessment Tools (NSATs)—such as LEED-ND and BREEAM Communities—evaluate urban sustainability at the neighbourhood level, reflecting an evolution from building-specific certifications to area-based methodologies. These instruments assess criteria including accessibility, mobility, environmental quality, and community participation, aligning with multiple SDG targets (Pulgar Rubilar et al., 2023).

Planning concepts such as the “15-Minute City” and the “Neighbourhood Unit” demonstrate the potential of neighbourhood-scale planning to reduce automobile dependence, promote equity, and enhance service accessibility (Brunetta et al., 2023). These approaches have gained recognition for their contribution to achieving SDG 11—Sustainable Cities and Communities—and are increasingly incorporated into urban policy frameworks.

Progress in geospatial data analysis and remote sensing now facilitates more precise monitoring of SDG indicators at the neighbourhood scale. These technologies enable disaggregation of data related to land use, density, and accessibility, thereby identifying vulnerable areas and informing more effective resilience strategies (Aquilino et al., 2021). Similarly, practical instruments such as Neighbourhood Impact Studies (EIVs) assist municipalities in anticipating and mitigating the effects of large-scale urban transformations, aligning planning efforts with SDG targets (Bittencourt et al., 2024).

In conclusion, the neighbourhood scale presents an effective balance of operational specificity, community engagement, and analytical precision. It connects global frameworks with local realities, serving as an essential platform for testing, implementing, and refining sustainability strategies in ways that are both comprehensive and integrated into everyday urban life.

1.2. WALKABILITY

INDICATOR

1.2.1
Road surface dedicated to pedestrian pathways

DESCRIPTION

The percentage ratio between the road surface dedicated to sidewalks [in km²] and the total road surface [in km²].

FORMULA FOR CALCULATION

i = Stm/St * 100

DATA FOR CALCULATION

Total road surface	0.145 Kmq
Superficie road surface dedicated to sidowalk	0.034 Kmq

RESULT

● **SUFFICIENT: 23.6%**

INDICATOR

1.2.3
Safety of the road network

DESCRIPTION

Ratio between the number of pedestrain crossings [At, n] every 100 meters [L, m].

FORMULA FOR CALCULATION

i = At/L

DATA FOR CALCULATION

Total lenght totale of road network	12.392 Km
Number of pedestrian crossings	111

RESULT

● **GOOD: 0.89** (n/100 meters)

Fig. 3: The Neighborhood as a Strategic Scale: A sample calculation of indicators summary created to assess two chosen indicators.
source: Saiu, V. et al., 2024

1.2.2 Criticalities and limitations of the SDG framework

The Sustainable Development Goals (SDG) framework, recognized as a comprehensive roadmap for global sustainability, presents notable structural and conceptual challenges concerning its adaptability, measurement protocols, and practical application at local scales.

Adaptability issues stem from the complexity of applying universal objectives within diverse contexts. Despite the SDGs' global design, they encounter variations in development stages, institutional frameworks, and policy environments across regions (Biermann, Kanie, & Kim, 2017). This contrasts with the standardized approach of the Millennium Development Goals, as effective sustainability assessment requires contextual adaptation. Successful implementation demands customized approaches and locally relevant indicator methodologies, ideally developed in partnership with regional experts (Biermann, Kanie, & Kim, 2017; Ahmed et al., 2024). Unfortunately, limited technical and financial capacity often hinders this localization process, particularly at municipal levels (Alonso Frank & Mattioli, 2023).

Measurement challenges directly relate to data quality and availability concerns. Substantial data gaps, methodological inconsistencies, and insufficient disaggregation—particularly at sub-national and neighborhood levels—compromise comprehensive reporting and accurate assessment (Simon et al., 2016). Many developing regions experience limitations in statistical capacity for generating reliable, current datasets (Oxoli et al., 2023), while elsewhere, data collection functions as an administrative requirement rather than a strategic policy resource (Siragusa et al., 2021). The absence of current information diminishes the value of existing datasets (Gazzarri, 2023), and obtaining accurate, timely data typically requires dedicated administrative efforts (Das et al., 2022).

Indicator relevance represents another significant concern. The framework's hierarchical structure often fails to capture context-specific nuances or the comprehensive scope of intended outcomes. For example, indicators for SDG 11.7 may inadequately address aspects of safety, inclusivity, accessibility, and environmental quality, potentially leading to imprecise evaluations or suboptimal resource distribution (Wang et al., 2024). Additionally, the extensive number of indicators (230) may promote reductive approaches to complex sustainability issues, undermining comprehensive assessment initiatives (Superti et al., 2021).

Finally, potential priority conflicts arise from the independent development of individual SDGs. While the framework aims to balance economic, social, and environmental dimensions, this equilibrium is not consistently maintained within specific goals. These structural inconsistencies create "policy loopholes" that enable selective implementation based on political considerations, potentially generating trade-offs and unintended consequences (Machingura, 2017).

When applied at the neighborhood level, the SDGs framework encounters substantial implementation challenges, limiting its effectiveness and monitoring capabilities.

Structural Limitations:

A primary structural constraint involves the insufficient availability and fragmentation of granular, high-quality data at the neighborhood scale. Standard statistics and global datasets typically aggregate at broader urban levels, failing to represent local conditions and intra-urban variations essential for meaningful evaluation (Saiu et al., 2024). Acquiring reliable neighborhood-level data requires substantial resources and faces challenges including accessibility issues, privacy considerations, and inconsistent local information systems (Pignatelli et al., 2023). These factors significantly constrain the development of actionable, neighborhood-specific insights.

Furthermore, existing SDG indicators and assessment methodologies are not optimally designed for neighborhood application. These metrics, primarily developed for national or city-wide monitoring, frequently lack local relevance (Pulgar Rubilar et al., 2023). Many evaluation frameworks inadequately address the full spectrum of sustainability dimensions, emphasizing environmental factors while underrepresenting social, economic, and institutional elements (Pulgar Rubilar et al., 2023). The limited automation, reproducibility, and compatibility with standard urban planning tools further restrict their practical utility for localized SDG implementation (Geremicca & Bilec, 2024).

Conceptual Limitations:

A fundamental conceptual challenge involves the lack of standardized “neighborhood” definitions and resulting measurement inconsistencies. Without universal definitions for urban areas or neighborhoods, significant discrepancies emerge when applying SDG indicators across different environments (Simon et al., 2015). Administrative boundaries rarely correspond with actual social or functional neighborhood zones. These misalignments generate “scale effects” and “zoning issues” that can distort assessments, creating a “prosperity illusion” in aggregated data while obscuring local disparities, thereby complicating targeted interventions (Wang et al., 2024).

The framework also faces challenges in evaluating interconnections and managing compromises at the neighborhood level. Though designed as an integrated system, SDG implementation often reveals that progress in certain areas may create “negative externalities” or unintended effects elsewhere (Machingura, 2017). Current monitoring approaches struggle to quantify and address these complex interdependencies (Trane et al., 2023), creating analytical gaps that result in disconnected or counterproductive neighborhood initiatives.

Finally, insufficient local governance capacity and stakeholder engagement present significant implementation barriers. Many local administrations lack the necessary human, technical, and financial resources to effectively implement global objectives at the neighborhood scale (Patole, 2018). Importantly, authentic community participation and stakeholder involvement are often inadequate. While essential for developing customized, bottom-up strategies that address specific neighborhood requirements, meaningful participation is frequently undervalued or ineffectively facilitated (Alsherfawi Aljazaerly et al., 2024). This disconnection between top-down policies and community realities fundamentally constrains effective SDG implementation.

Category of Limitation	Description
Adaptability Issues	The SDG framework struggles with diverse contexts due to varying development stages and policy environments. **Effective sustainability assessment needs customized approaches**with regional experts. Municipal levels often face**limited technical and financial capacity** for localization.
Measurement Challenges	**Data quality and availability concerns**create significant obstacles. **Data gaps, methodological inconsistencies, and insufficient disaggregation** compromise assessment, particularly at sub-national levels. Many regions lack statistical capacity, while others treat data collection as administrative rather than strategic. **Outdated information reduces dataset value**, and obtaining current data requires substantial effort.
Structural Limitations (at neighbourhood level)	Key constraints include**insufficient granular data at neighbourhood scale.** Standard statistics aggregate at broader levels, missing local conditions. Neighborhood-level data acquisition faces resource constraints, accessibility issues, and inconsistent systems. SDG indicators are**not optimized for neighbourhood application**and often lack local relevance. Many frameworks emphasize environmental factors while underrepresenting social, economic, and institutional dimensions, with limited compatibility with urban planning tools.
Conceptual Limitations (at neighbourhood level)	The framework struggles with interconnections and trade-offs. Progress often creates**"negative externalities"**elsewhere. Current approaches inadequately address these **complex interdependencies**, leading to disconnected initiatives. The **lack of standardized "neighborhood" definitions** creates measurement inconsistencies. Administrative boundaries rarely match functional zones, causing**"scale effects" and "zoning issues"**that mask local disparities.
Local Governance & Engagement Shortcomings	Local administrations often**lack necessary resources**to implement global objectives locally. Community participation, though essential for customized strategies, is**undervalued or ineffectively facilitated.** This disconnection between policies and community realities constrains effective implementation.

Table 1: Challenges and constraints of the SDG framework.

1.3 Digital tools for urban data visualization and assessment

1.3.1 Digital platforms

1.3.1.1 Definition

Digital platforms, in the context of urban sustainability and data visualization, represent virtual environments that leverage advanced technologies to facilitate sustainable urban development and enhance understanding of urban dynamics (Katmada et al., 2023). They serve as data-centered and digitally-enabled socio-technical assemblages deeply rooted in the urban system, fostering new social and material relationships (Katmada et al., 2023). These platforms are crucial components of smart city initiatives and the broader concept of platform urbanism, designed to address complex challenges arising from rapid urbanization and the imperative for sustainable practices (Katmada et al., 2023). Their emergence is driven by the proliferation of digital Information and Communication Technologies (ICTs) and the increasing availability of urban data, transforming traditional urban planning into more informed and collaborative processes (Katmada et al., 2023).

The role of digital platforms in data visualization for urban sustainability is paramount. They enable the comprehensive collection, processing, and display of heterogeneous urban data, which is essential for city managers and citizens to monitor urban performance and discern trends (Katmada et al., 2023). Urban dashboards, a common application of these platforms, consolidate urban information into a single view, providing access to data visualizations that reflect a city's performance against selected indicators (Katmada et al., 2023). These tools go beyond mere graphical displays, offering rich, context-based representations that provide deeper insights into underlying patterns and trends (Farmanbar & Rong, 2020). Geographic Information Systems (GIS) tools are frequently embedded within these platforms, allowing for the integration of large datasets with high levels of realism and detail, thereby facilitating effective data visualization and management in a spatial context (Pignatelli et al., 2023). The goal is to make complex urban data readily interpretable, supporting evidence-based decision-making for sustainable development (Appleton & Lovett, 2005).

Key features define these digital platforms:

- **Interactive and Real-time Capabilities:** A defining characteristic is their ability to support interactions and transactions in real-time or near-real time (Katmada et al., 2023). This dynamism is vital for capturing the continuously evolving nature of urban systems and enabling proactive responses to challenges (Geremicca & Bilec, 2024). Dashboards, for instance, are designed to display continuously updated data, providing an immediate snapshot of urban conditions (Farmanbar & Rong, 2020).

- **Data Aggregation, Processing, and Analysis:** Digital platforms are designed to gather, process, and visualize extensive datasets related to various urban activities, including mobility patterns, energy consumption, and environmental quality (Katmada et al., 2023). They function as centralized "observatories" or data aggregators, collecting and providing urban data that can drive research, technology transfer, and commercialization efforts (Rehm et al., 2021). These platforms are equipped to handle large volumes of data and perform intensive operations efficiently, often leveraging cloud computing infrastructures (Syrmos et al., 2023).

- **Integration of Diverse Data Sources and Technologies:** These platforms seamlessly integrate information from a multitude of sources, such as IoT devices, environmental sensors, GIS, and remote sensing imagery, alongside crowdsourced data (Costa et al., 2024). This multidisciplinary integration provides a holistic understanding necessary for addressing multifaceted urban challenges (Pignatelli et al., 2023).

- **Support for Decision-Making and Planning:** They are developed to aid decision-makers in formulating sustainable urban planning strategies and co-creating future transition pathways through the use of spatialized outputs (Pignatelli et al., 2023). By analyzing trends and patterns derived from integrated data, these platforms facilitate more informed choices and targeted interventions that aim to improve urban liveability and sustainability (Costa et al., 2024).
- **Multi-scale and Spatial Capabilities:** Urban platforms function as adaptable templates, capable of application across various geographical scales, from neighborhood to metropolitan, underscoring the inherently spatial configuration of platform urbanism (Katmada et al., 2023). The embedded GIS tools are fundamental to this feature, allowing planners to analyze spatial patterns and relationships crucial for location-based decisions (Katmada et al., 2023).
- **Participatory and Collaborative Features:** Many digital platforms are specifically designed to foster citizen participation in urban planning and development processes (Katmada et al., 2023). They support collaborative governance models, including features for participatory budgeting and broader citizen engagement in decision-making (Katmada et al., 2023). Urban Experimentation Platforms (UXPs), for example, utilize digital platforms to coordinate policy measures and promote collective intelligence, driving socio-technical transformations at the local level (Rehm et al., 2021).
- **Openness and Accessibility:** Initiatives like “Open-Data” platforms exemplify the commitment to making public datasets readily available, enhancing transparency and encouraging broader participation in urban development (Costa et al., 2024). These platforms are often web-based and offer reproducible methodologies, promoting widespread access and utility (Pignatelli et al., 2023).

These features collectively define digital platforms as powerful tools for advancing urban sustainability by transforming how cities are understood, managed, and collaboratively developed.

1.3.1.2 Typologies

Several types of digital platforms are employed for these purposes:

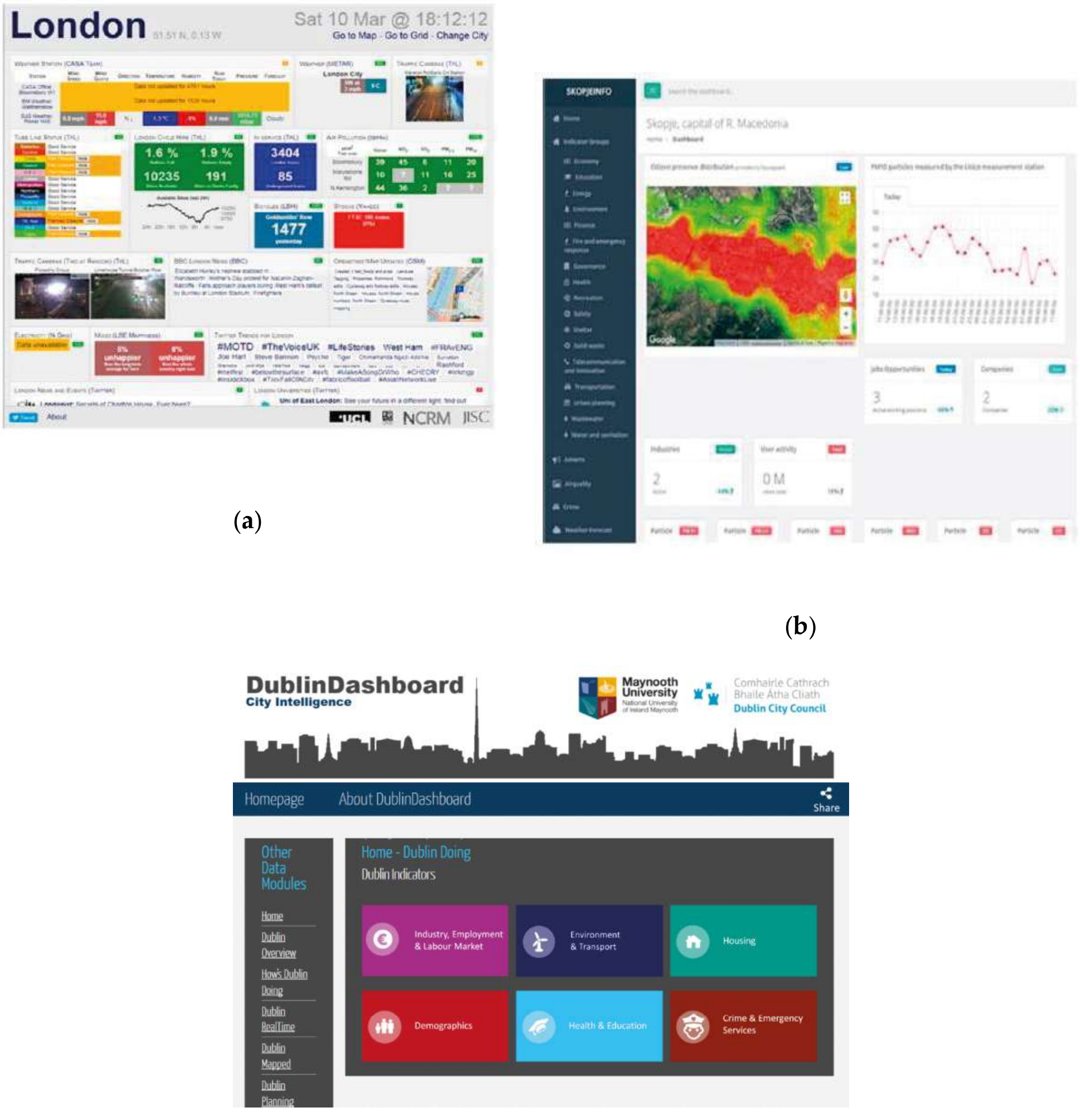
Spatial Decision Support Systems (SDSS) assist decision-makers in sustainable urban planning through interactive dashboards. They enable co-creation of transition strategies via spatialized outputs and KPI assessment (Pignatelli et al., 2023). Integrating GIS tools, they manage large volumes of georeferenced data and present clear results for evidence-based urban development decisions (Pignatelli et al., 2023).

Urban Data Platforms gather, process, and visualize datasets on urban activities like mobility, energy use, and air quality to inform decision-making (Katmada et al., 2023). These include analytics platforms, dashboards, and data portals that provide urban insights (Katmada et al., 2023). They integrate multiple data sources including IoT devices, sensors, and remote sensing imagery (Costa et al., 2024). Many follow “Open-Data” principles, promoting transparency and participation (Costa et al., 2024).

Urban Digital Twins (UDT) create dynamic virtual replicas of cities’ physical and functional attributes (Bibri et al., 2024). These models mirror urban structures and dynamics in real-time, allowing governments to simulate scenarios and test solutions (Bibri et al., 2024). Enhanced by AI technologies, they enable detailed analysis and visualization for sustainability interventions (Bibri et al., 2024; Geremicca & Bilec, 2024).

Urban Crowdsourcing Platforms enable citizen engagement in urban planning processes by leveraging collective intelligence (Katmada et al., 2023). Citizens identify improvement areas, provide design feedback, or fund initiatives through crowdfunding (Katmada et al., 2023).

Collaborative Governance Platforms foster interaction and collective decision-making among city stakeholders (Katmada et al., 2023). They support participatory budgeting, urban co-creation, and access to governance information, promoting inclusive management practices (Katmada et al., 2023). Many advocate open-source approaches as alternatives to proprietary e-participation software (Katmada et al., 2023).



(a)

(b)

(c)

Fig. 4: Digital platform typologies: Visual examples of dashboard interfaces: (a) London CityDashboard with single-page row organization; (b) Skopje dashboard with menu-based drill-down structure; (c) Dublin dashboard using menu-based drill-down navigation.
source: Farmanbar & Rong, 2020.

1.3.1.3 Examples from real-world case studies

Spatial Decision Support Systems (SDSS) and GIS-based Frameworks:

SDSS, often integrating Geographic Information Systems (GIS) and Multi-criteria Analysis (MCA), support decision-makers in spatial issues by combining quality of life, technology, and environmental respect (Bisello et al., 2017). An example is the interactive dashboard developed for the MOLOC European Interreg Project, applied to the city of Turin. This tool enables the evaluation of urban sustainability performance through Key Performance Indicators (KPIs) and supports scenario development by providing targeted suggestions for local development planning. The spatial distribution of results helps identify city strengths and weaknesses, aiding the implementation of low-carbon action plans and preventing unnecessary investments (Pignatelli et al., 2023). Similarly, the urbanZEB platform has been utilized for long-term energy renovation strategies in the Basque Country and the Barcelona Metropolitan Area, providing building-by-building diagnoses and prioritizing interventions in vulnerable areas (Civiero et al., 2021). The E-City web platform, implemented in Oeiras, Portugal, exemplifies a tool for planning energy balance at the urban scale, integrating with existing municipal GIS to organize and visualize energy performance data, thereby supporting energy-efficient urban development (Amado et al., 2018).

Urban Digital Twins (UDT):

UDTs are dynamic virtual replicas of a city’s physical, spatial, and functional aspects, mirroring their structures and dynamics in real-time. They are powerful tools for local governments to simulate “what-if” scenarios and potential solutions for diverse urban conditions, especially for advancing environmental sustainability goals (Bibri et al., 2024). In Patras, a digital twin project leverages citizen feedback data and advanced technologies to optimize urban functionality, strengthen resilience, and improve residents’ quality of life. This platform learns from historical and real-time data to inform decisions, aiding city planners and policymakers in addressing complex urban challenges (Gkontzis et al., 2024).

Urban Data Platforms:

These platforms collect, process, and visualize large datasets about city activities such as mobility patterns, energy usage, and air quality to inform urban decision-making (Katmada et al., 2023). UrbanSim, an open-source platform, supports land use, transportation, and environmental planning by integrating diverse data sources and allowing customization for local conditions. It has been used globally to model urban development, assess policy impacts, and generate future scenarios (Katmada et al., 2023). Another instance, the Urban Thematic Exploitation Platform (U-TEP), combines open access to multi-source data repositories with processing, analysis, and visualization functionalities to support evidence-based urban studies and monitor land-use dynamics (Esch et al., 2020).

Participatory and Collaborative Governance Platforms:

Digital platforms increasingly enable active citizen participation in urban planning and decision-making, moving beyond top-down approaches (Katmada et al., 2023). Collaborative governance platforms facilitate citizens in expressing opinions, debating urban issues, and participating in budgeting. Examples include Decide Madrid and Decidim Barcelona, which promote open-source, commons-based democratic approaches for e-participation and have been used for crowdsourcing citizen proposals on projects like green area design and strategic city plans (Streitz & Konomi, 2023). OmaStadi in Helsinki, built on the Decidim platform, allows residents to propose and vote on ideas for urban development and improvement, leading to projects like park illumination with renewable energy and increased tree planting (Katmada et al., 2023).

These diverse digital platforms demonstrate the transformative potential of technology in fostering more sustainable, resilient, and inclusive urban environments by enabling data-driven insights, citizen engagement, and efficient resource management.

1.3.1.4 Limits of the tools

Current digital platforms employed in urban data visualization and sustainability monitoring encounter several significant limitations and challenges that impede their effectiveness and widespread adoption in achieving sustainable urban development goals. These issues span across technical, financial, social, and ethical domains.

One primary limitation is the **data availability, quality, and consistency** (Lami et al., 2024). Urban sustainability assessment requires a large volume of spatially-based indicators, yet existing databases often exhibit inhomogeneity, affecting their potential utility. The availability and the spatial and temporal scale of data can be inconsistent, limiting the depth and accuracy of analyses. For example, remote sensing data, while abundant, can suffer from insufficient spatial and temporal resolution, and high-resolution data often comes with prohibitive costs or added noise, making it difficult to capture rapidly changing urban dynamics or fine-scale features required for precise monitoring.

A critical technical challenge is **interoperability and standardization** among diverse technologies (Bibri et al., 2024). The seamless integration of various components within the smart city ecosystem, such as Internet of Things (IoT) devices, sensors, data platforms, and analytical tools, is frequently hindered by a lack of standardized protocols and frameworks. This heterogeneity results in proprietary systems operating in silos, which impedes the fluid exchange of contextualized information necessary for comprehensive urban modeling and simulation, like that required for urban digital twins.

Furthermore, these platforms often demand **high technical expertise and complexity** to operate effectively (Frantzeskaki et al., 2025). The interdisciplinary nature of urban sustainability necessitates coordination among diverse fields such as urban planning, engineering, and data science. The absence of a standardized approach for creating, curating, and executing analytical models means that many research-derived decision-support tools remain as prototypes, failing to transition into sustainable, widely usable applications due to the specialized knowledge required for bespoke software development.

Resource allocation and financial constraints present a formidable barrier to the implementation and sustainability of advanced digital platforms (Bibri et al., 2024). Developing and maintaining such systems, especially AI/AIoT-driven urban digital twins, requires substantial initial investments in technological infrastructure, including sensor networks, data storage, and computation resources, along with ongoing operational costs. These financial demands often surpass the budgetary capacities of urban planning initiatives, particularly in developing countries, making their promotion and acceptance challenging.

In terms of social dimensions, a significant challenge lies in **user engagement and inclusivity**, as many digital tools for urban planning are developed with a top-down approach (Katmada et al., 2023). This often leads to reduced citizen participation, resulting in decision-making processes that may lack inclusivity, diversity, and trust. Issues like participation bias and varied digital literacy among users further limit the accessibility and effective engagement of all stakeholders. Neglecting the socio-economic and cultural contexts can inadvertently exacerbate existing urban inequalities, as technological solutions might not align with the genuine needs and aspirations of diverse communities.

Ethical concerns and data bias are also prevalent (Gkontzis et al., 2024). Many advanced analytics, including machine learning algorithms, rely heavily on historical data, which may inherently contain biases. If not addressed rigorously, these biases can lead to unfair or discriminatory outcomes in public services and urban management. Additionally, the design and presentation of data through urban dashboards can be ideologically and politically framed, potentially obfuscating certain urban realities and influencing how users interpret information.

Finally, the reliance on **proprietary platforms and their inherent limitations** poses a challenge (Streitz & Konomi, 2023). Many digital tools for urban data visualization and sustainability monitoring are built on proprietary software or commercial platforms. This can lead to vendor lock-in and significant risks, as the discontinuance or malfunction of these proprietary services can result in the loss of data, including valuable user-generated content, thereby undermining the continuity and reliability of monitoring efforts. This contrasts with the need for open, reproducible, and scalable solutions for urban research and planning.

1.3.2 Georeferenced indicators

1.3.2.1 Definition

Georeferenced indicators, in the context of urban data visualization and assessment, are quantifiable measures inherently linked to specific geographic locations, offering insights into the state and performance of urban systems over time (Kitchin et al., 2015).

These indicators simplify the complex concept of urban sustainability by providing metrics that describe phenomena within the urban environment (Khodakarami et al., 2023). The “georeferenced” aspect implies that data points, derived from various sources such as sensors or surveys, are assigned precise spatial coordinates, enabling their integration and analysis within a geographical context (Costa et al., 2024). This spatialization is fundamental for urban visualization, facilitating the display of analytical results in formats like raster or polygon maps, which effectively illustrate the distribution of socioeconomic and ecological data (Yeh, 1999).

Geographic Information Systems (GIS) are pivotal tools in this process, enabling the integration of large and diverse datasets with a high degree of realism and detail, and supporting the creation of spatial models structured with multiple layers of georeferenced information (Pignatelli et al., 2023). The resulting visualizations are clear and readily interpretable, even when the underlying spatial model is complex, which significantly aids decision-making by allowing stakeholders to observe the geographical dynamics of urban areas and identify patterns, trends, and anomalies (Appleton and Lovett, 2005).

The relationship between georeferenced indicators and sustainable urban planning is critical, as these indicators are indispensable for evaluation, measurement, and reporting within decision-making processes concerning urban sustainability (Higgs et al., 2025). Sustainable urban planning necessitates a multidisciplinary and multi-criteria methodological approach that considers economic, social, and environmental subsystems to foster efficiency and innovation with minimal resource consumption (Pignatelli et al., 2023). Georeferenced indicators support this by allowing the simultaneous incorporation of diverse criteria, thereby providing a comprehensive assessment of urban performance (Lombardi et al., 2017). For example, they can reveal unsustainable trends like urban sprawl or guide the efficient management of resources in disadvantaged urban areas (Caselli et al., 2020).

The spatial evaluation of Key Performance Indicators (KPIs) is central to the development of Spatial Decision Support Systems (SDSS) for sustainable urban planning (Pignatelli et al., 2023). These systems assist decision-makers in co-creating future transition strategies by offering spatialized outputs that highlight a city’s strengths and weaknesses, thus facilitating the implementation of targeted action plans and avoiding unnecessary investments (Pignatelli et al., 2023).

Furthermore, georeferenced indicators facilitate the assessment of urban sustainability across various scales, from the broader city level to the more granular neighborhood scale (Khodakarami et al., 2023). This detailed assessment is crucial because many urban sustainability challenges manifest at the neighborhood level, directly impacting daily human interactions and socio-spatial vitality (Alsherfawi Aljazaerly et al., 2024). Indicators pertaining to urban ecosystem services, environmental hazards, and urban structure—such as accessibility to public services and green spaces—are spatially mapped and integrated using multi-criteria decision analysis (MCDA) within GIS environments to generate comprehensive sustainability maps (Khodakarami et al., 2023).

This spatially-based assessment equips urban planners with valuable insights for operational actions aimed at achieving Sustainable Development Goals (SDGs) (Khodakarami et al., 2023). The United Nations' 2030 Agenda emphasizes the localization of SDGs, acknowledging that a significant proportion of SDG indicators contain an "urban component," which underscores the indispensable role of detailed, intra-urban scale indicators for effective policy design and monitoring (Gervasi et al., 2024; Aquilino et al., 2020). Moreover, the use of georeferenced data fosters participatory planning processes by enabling stakeholders to visualize and comprehend complex urban issues, thereby promoting collaboration and consensus-building for the development of more resilient and sustainable cities (Katmada et al., 2023). Advanced technologies like Artificial Intelligence (AI) and Urban Digital Twins (UDT) further enhance these capabilities, leveraging georeferenced data for predictive modeling, scenario simulations, and real-time monitoring to optimize environmental strategies and cultivate resilient, environmentally conscious urban environments (Bibri et al., 2024).

1.3.2.2 Typologies

The main typologies of georeferenced indicators typically include those related to urban structure and morphology, environmental quality, socio-economic aspects and accessibility, and urban governance and planning processes.

Urban Structure and Morphology Indicators:

These indicators quantify the physical characteristics and spatial organization of urban areas, providing insights into their form, density, and connectivity. They measure aspects such as building density, the geometric shape and structure of city blocks and neighborhoods, and overall urban morphology (Tretiak, 2024). For instance, street network analysis employs metrics like intersection density, linear street density, average street segment length (as a proxy for block size), and topological properties such as connectedness, centrality, and resilience. These measures help to characterize the qualitative nature of street networks, distinguishing between fine-grained, dense urban fabrics and coarse-grained, sparse ones (Boeing, 2017). This typology also encompasses measures of urban sprawl, assessed through the ratio of land consumption rate to population growth rate (e.g., SDG Indicator 11.3.1), and general settlement typology, by analyzing developed land use or built-up land cover (Cardenas-Ritzert et al., 2024). Further, urban form can be evaluated using indicators like compactness, floor area ratio, and urban porosity, while transport network connectivity is measured via block density and street density (Khodakarami et al., 2023). These indicators are fundamental for understanding how urban areas are physically structured and evolve, directly informing spatial planning decisions for sustainable development.

Environmental Quality Indicators:

This typology focuses on measuring the environmental health and ecological performance of urban environments. Key measures include the assessment of urban ecosystem services, such as carbon sequestration, the alleviation of urban temperature through cooling effects, and the reduction of stormwater runoff (Khodakarami et al., 2023). Indicators also monitor specific environmental hazards like noise pollution (Khodakarami et al., 2023) and broader aspects of air quality (Costa et al., 2024). The quality and quantity of green urban areas (GUA) are quantified, often by measuring the area of GUA per capita or assessing accessibility based on proximity, such as the proportion of the population within a certain walking distance of green spaces (Lorenzo-Sáez et al., 2021). Energy performance is another critical dimension, with indicators related to building energy ratings, residential energy consumption, and greenhouse gas emissions (Gervasi et al., 2024). The habitat quality and biological diversity within urban ecosystems are also assessed, reflecting the overall resilience and ecological functionality of the territory (Brunetta et al., 2023). These indicators are essential for evaluating the environmental impact of urban development and guiding strategies for climate change adaptation and resource efficiency.

Socio-Economic and Accessibility Indicators:

This category addresses the social dimensions of urban living, including demographic characteristics, access to essential services, and various measures of urban vitality. Common metrics involve population density (Mumtaz et al., 2025), and socio-economic vulnerability factors such as low income and aging population (Civiero et al., 2021). Accessibility is frequently measured through indicators like the proximity of residential buildings to key public human services, including health facilities, educational institutions, and public green spaces (Pignatelli et al., 2023). Public transport accessibility is quantified by determining the proportion of the population within a convenient walking distance (e.g., 500 meters) to the nearest stop (Aquilino et al., 2021). Indicators also monitor housing conditions, such as housing per capita volume and building crowding (Aquilino et al., 2021), and the proportion of the urban population residing in slums, informal settlements, or inadequate housing (Lami et al., 2024). Urban vibrancy and quality of life are assessed through measures like the spatial distribution of points of interest (POIs) classified into categories such as civic, recreational, entertainment, food, healthcare, institutional, social, and commercial, reflecting the mix of urban activities and services (Yap & Biljecki, 2023). Additionally, indicators like crime rates are used to understand social safety and well-being (Wang et al., 2024). These indicators are crucial for identifying social inequalities, improving urban liveability, and ensuring equitable access to resources and opportunities.

Urban Governance and Planning Process Indicators:

This typology focuses on the effectiveness and inclusivity of urban planning and management processes. These indicators often evaluate the mechanisms for public participation and the transparency of decision-making. Measures include the existence of direct participation structures of civil society in urban planning and management, and their regular, democratic operation (Lami et al., 2024). They can also involve assessing the municipal government's capacity to influence specific indicators related to sustainable urban development strategies (Koch et al., 2023). Qualitative indicators, such as "milestone events," gauge phenomena of exclusive or prevailing competence of the municipality, while quantitative indicators assess shared competencies among different municipalities or contextual phenomena (Gazzarri, 2023). The variety of urban strategic planning processes undertaken in a territory can also serve as a strategic culture indicator (Trane et al., 2023). These indicators are instrumental in ensuring accountability, fostering citizen engagement, and guiding the development and implementation of urban policies towards more transparent, data-driven, and evidence-based governance for sustainable urban futures (Kitchin et al., 2015).

Typology	Description and Examples
Environmental Quality Indicators	Measure urban environmental health and ecological performance. Examples: Urban ecosystem services(carbon sequestration, cooling), pollution levels, green areas(GUA per capita, accessibility), energy performance(building ratings, emissions)and biodiversity. Purpose: Guide climate adaptation and resource efficiency strategies.
Socio-Economic and Accessibility Indicators	Address social dimensions and service access. Examples: Population density, vulnerability factors, proximity to services, transport accessibility, housing conditions, urban vibrancy and crime rates. Purpose: Identify inequalities and improve urban livability.
Urban Governance and Planning Process Indicators	Focus on planning effectiveness and inclusivity. Examples: Civil society participation structures, municipal capacity, qualitative indicators and strategic planning processes. Purpose: Ensure accountability and data-driven governance for sustainable urban futures.

Table 2: Typologies of georeferenced indicators.

1.3.2.3 Examples from real-world case studies

One significant real-world application is in the **city of Turin, Italy**, where a multidisciplinary GIS-based framework and an interactive dashboard were developed to evaluate the city's sustainability performance using Key Performance Indicators (KPIs) (Pignatelli et al., 2023). This tool supports decision-makers in co-creating future transition strategies and allows for spatial evaluation of KPIs, identifying urban strengths and weaknesses to facilitate low-carbon action plans. The methodology, part of the MOLOC European Interreg Project, is designed to be adaptable to other European urban contexts.

For direct SDG monitoring at a local scale, the **city of Bari, Southern Italy**, implemented georeferenced indicators for SDG 11, focusing on urban social resilience and migration fluxes (Aquilino et al., 2020). By integrating Sentinel-2 imagery and updated census information, researchers disaggregated data to a 100x100 meter grid, quantifying indicators like the proportion of the regular migrant population living in inadequate housing (SDG 11.1.1) and the ratio of land consumption rate to migrant population growth rate (SDG 11.3.1). This detailed spatial information helps urban planners and decision-makers manage increasing migration pressure and monitor Agenda 2030 progress.

In **Isfahan Metropolitan, Iran**, georeferenced indicators were effectively used for a spatially-based urban sustainability assessment at the neighborhood scale (Khodakarami et al., 2023). This integrated framework combined spatial modeling and multi-criteria decision-making analysis to evaluate sustainability across three categories: ecosystem services (e.g., carbon sequestration), environmental hazards (e.g., noise pollution), and urban structure (e.g., urban form and transport network connectivity). The granular spatial distribution maps revealed central areas as more sustainable, guiding urban planners toward operational actions for sustainable development.

Barcelona Metropolitan Area provides another example, utilizing the urbanZEB tool to prioritize energy renovation interventions (Civiero et al., 2021). This tool allowed for building-by-building diagnoses of over a million dwellings, representing a significant advancement in large-scale renovation strategies by identifying areas of special vulnerability for targeted energy efficiency improvements at the metropolitan scale.

In **Washington, D.C., USA**, a public-access Geographic Information System (GIS) and Tableau dashboards were developed for comprehensive urban green infrastructure (UGI) planning (Taylor et al., 2021). This tool enables stakeholders to identify existing UGI and potential areas for new UGI, including urban agriculture, by manipulating data and applying population vulnerability indices. This supports equitable UGI development, particularly in food deserts and underserved wards.

The **city of Xi'an, China**, employed a multi-scale assessment model for SDG 11.7, which aims to promote the improvement of urban public spaces (Wang et al., 2024). This top-down problem-solving approach constructed an indicator framework for apartment complexes, street blocks, and counties, then integrated these scales to generate city-level results. The model effectively captures safety, inclusiveness, accessibility, and greenness through 11 indicators, guiding future development directions for various government levels.

Globally and regionally, **geospatial data and remote sensing techniques** are crucial for monitoring various SDGs, including poverty alleviation (Avtar et al., 2020). Studies have leveraged high-resolution satellite imagery and machine learning to map poverty in data-scarce regions like Africa and Sri Lanka, using features such as paved road density, building density, and roof types as proxies. These poverty maps serve as important tools for developing effective social protection policies and identifying potential hotspots for intervention.

Finally, **city dashboards** represent a broad application of georeferenced indicators for urban governance and management (Kitchin et al., 2015). Examples such as the Dublin Dashboard provide detailed spatial and time-series data about various urban aspects, enabling longitudinal studies of socio-spatial, economic, and environmental processes. These interactive visualizations serve as evidence bases for monitoring urban services, guiding policy formulation, and informing how cities are governed and regulated.

1.3.2.4 Limits of the tools

The use of georeferenced indicators for urban data visualization and assessment presents several significant limitations and challenges, impeding comprehensive and effective urban planning and Sustainable Development Goal (SDG) monitoring. These issues span data characteristics, methodological complexities, technological integration, and the fundamental interpretation of urban phenomena.

One primary challenge is **data availability, quality, and timeliness**. Urban data are often scattered across numerous entities, making collection a time-consuming and costly endeavor, especially at the city level (Pignatelli et al., 2023). There is limited availability and reliability of large, standardized databases, and public data sources are frequently outdated, diminishing their utility for real-time policy decisions (Pignatelli et al., 2023). Furthermore, privacy concerns can restrict access to granular data, forcing reliance on aggregated information which may sacrifice accuracy (Pignatelli et al., 2023). Ensuring data quality, consistency, and comparability across diverse sources and geographical contexts also remains a significant hurdle (Ahmed et al., 2024).

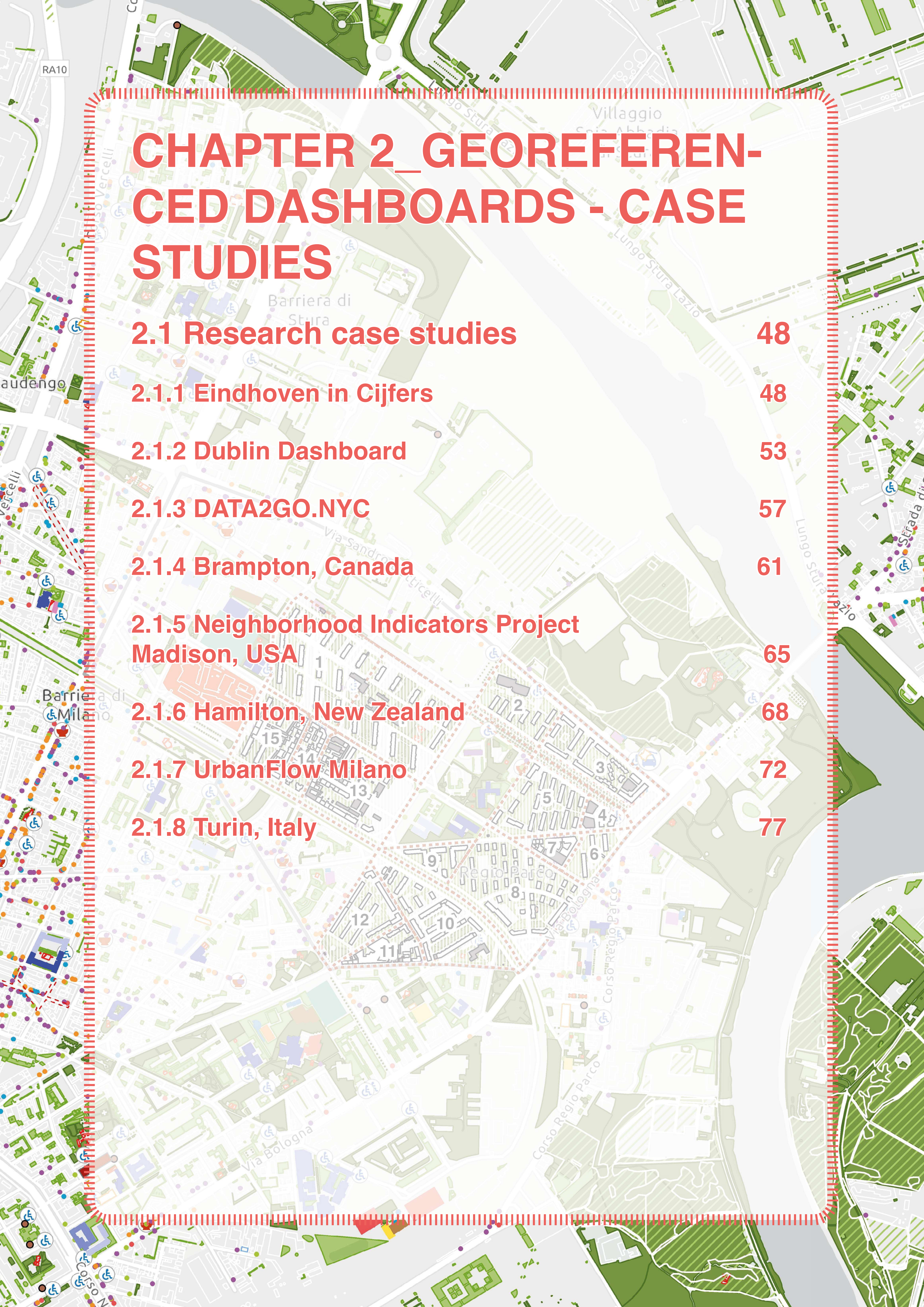
Another critical limitation stems from **scale and spatial resolution issues**. The Modifiable Areal Unit Problem (MAUP) is a well-known spatial challenge, where the arbitrary statistical geographies used for data collection and reporting can dramatically alter aggregated observations and influence policy interventions (Kitchin et al., 2015). This means that decisions over a city's statistical geography can profoundly impact its understanding and governance (Kitchin et al., 2015). Moreover, spatial products covering large extents often involve trade-offs in resolution and accuracy, leading to discrepancies in urban delineation and assessments and making consistent comparisons difficult over time or across different urban areas (Cardenas-Ritzert et al., 2024).

Methodological and technical complexities further complicate the effective use of georeferenced indicators. Current assessment tools often lack methodological sophistication, particularly in terms of spatial explicitness, and suffer from insufficient automation and reproducibility (Pignatelli et al., 2023). Indicators, especially composite ones, can be highly reductionist, simplifying complex urban relationships into one-dimensional measures that fail to capture the full, multi-dimensional picture of a city (Kitchin et al., 2015). Such simplified indicators may not reveal the root causes of problems, only their symptoms (Kitchin et al., 2015). Transparency is also an issue, as the underlying methodologies, including aggregation and weighting processes, are often "black-boxed" and not publicly documented (Kitchin et al., 2015).

The challenge of **data interoperability and integration** is pervasive. The diverse origins, formats, and functionalities of data from various urban sources (e.g., IoT devices, sensors, and different platforms) often result in proprietary systems operating in silos, creating significant barriers to seamless information exchange (Bibri et al., 2024). This fragmentation inhibits the real-time synchronization necessary for comprehensive modeling and undermines the collaborative potential of interconnected urban systems (Bibri et al., 2024). Without standardized protocols and frameworks for data sharing, achieving a unified, holistic view of urban dynamics remains difficult (Gkontzis et al., 2024).

Furthermore, **interpretability, bias, and contextualization** pose substantial challenges. Georeferenced indicators are not neutral entities; they are shaped by inherent beliefs, biases, and power inequalities within society (Koch et al., 2023). Relying on a “realist epistemology”—the idea that data objectively reflect the world as it truly is—can create a misleading illusion of comprehensive urban understanding (Kitchin et al., 2015). This can lead to an instrumental rationality that marginalizes qualitative insights and decontextualizes urban areas from their unique historical, political, and socio-economic contexts (Kitchin et al., 2015). The selection and weighting of indicators can also inherently favor certain locations or aspects, introducing subtle forms of manipulation and undermining unbiased assessment (Kitchin et al., 2015).

Finally, addressing the **dynamic nature of urban environments** with static data and models is a significant hurdle. Urban systems are constantly evolving, meaning real-time data are crucial for effective monitoring and planning. However, many traditional urban metabolism (UM) models and assessment tools only provide static glimpses of urban flows (Geremicca & Bilec, 2024). This lack of dynamic representation hinders the ability to capture rapid changes, understand evolving urban processes, and respond proactively to challenges like traffic congestion or waste management, which require continuous updates and real-time insights (Geremicca & Bilec, 2024).



CHAPTER 2_GEOREFERENCED DASHBOARDS - CASE STUDIES

The following chapter examines innovative case studies that showcase how digital platforms are transforming urban planning and civic engagement. These platforms demonstrate diverse approaches to visualizing spatial data, engaging citizens, and supporting evidence-based policy decisions.

A comparative analysis reveals common methodologies, technical challenges, and opportunities for replication across different urban contexts. This analysis highlights how georeferenced dashboards serve as essential tools for transparent governance and sustainable urban development.

2.1 Research case studies

2.1.1 Eindhoven in Cijfers

Research paper: **Dashboard as a Platform for Community Engagement in a City Development—A Review of Techniques, Tools and Methods**

Authors: Joanna Pluto-Kossakowska, Anna Fijałkowska and Sylwia Krzysztofowicz, Małgorzata Denis, Joanna Jaroszewicz

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The Eindhoven in Cijfers platform, a municipal initiative, is a sophisticated web-based dashboard designed for monitoring and communicating quality of life and sustainable urban development within the city of Eindhoven.

The platform functions as an efficient web-based solution that facilitates information exchange between the municipality and residents, presenting insights about the city's strengths and weaknesses in an accessible format. Furthermore, it offers analysis of specific events' impacts, such as the COVID-19 pandemic, on quality-of-life metrics. The dashboard employs a circular model to evaluate policy effectiveness over time, enabling informed adjustments to municipal strategies.

The platform utilizes a combination of commercial IT tools and open-source software such as Tableau for data management and visualization.
Eindhoven in Cijfers primarily focuses on the city of Eindhoven, with data stratified across multiple spatial levels—including citywide metrics, district-level information, and analysis of 117 distinct neighborhood areas—enabling detailed geographical assessment. Beyond serving local needs, the platform contributes to national benchmarking efforts by sharing select indicators via the Netherlands Statistical Office website, facilitating comparisons with other Dutch municipalities.

The development of Eindhoven in Cijfers reflects the evolution of contemporary urban planning, which increasingly prioritizes people, their quality of life, and fostering their active involvement in shaping the urban environment. Modern urban governance recognizes that informed civic participation requires residents to access data about their city's performance in an intuitive, interpretable format.

Web-based dashboards have emerged as effective solutions for facilitating this essential communication between municipal authorities and community members.
The platform's implementation aligns with global open data initiatives and legal frameworks, such as the EU's Open Data Directive, which require governments to make public sector

information accessible for reuse.

This commitment to data transparency enhances governmental accountability, enables evidence-based civic participation, and stimulates economic innovation through data utilization. A significant catalyst for the dashboard's enhancement was the COVID-19 pandemic, which demonstrated the necessity for real-time monitoring and effective communication of its impacts on urban life.

Eindhoven responded by implementing a specialized dashboard component to analyze these effects, demonstrating the platform's value in addressing unexpected challenges and supporting responsive policy interventions.

The interface design, with its comprehensive toolset and intuitive layout, aims to enhance civic awareness and strengthen resident engagement with municipal policies.

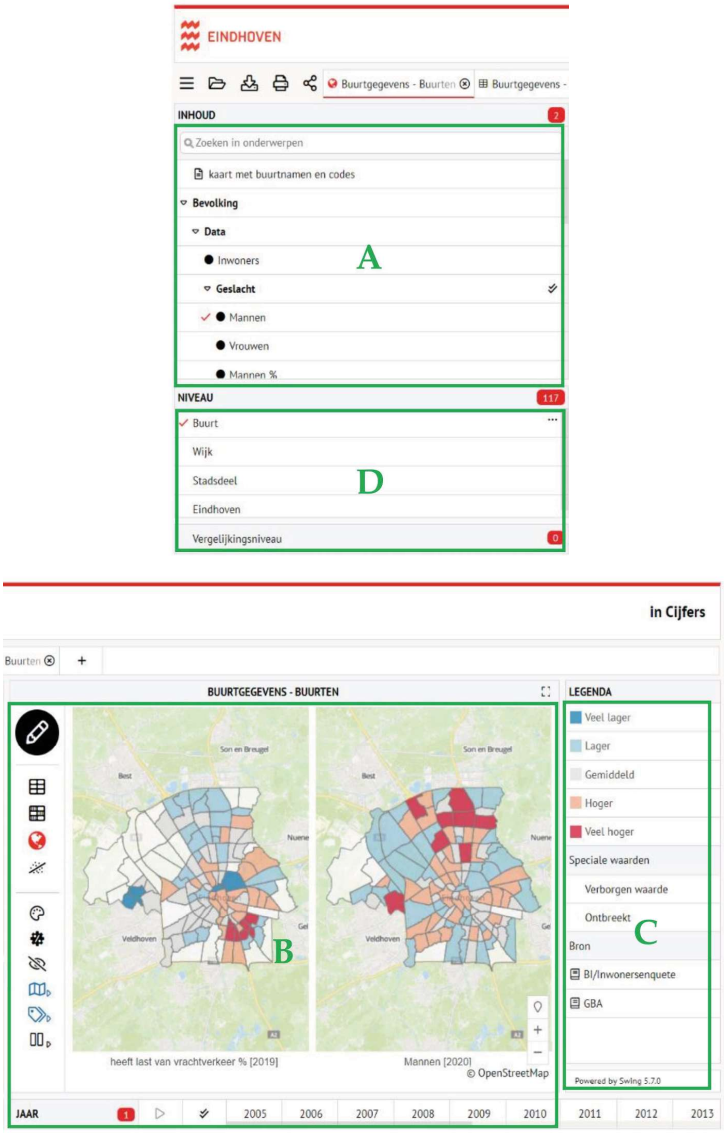


Figure 5: "Eindhoven in Cijfers" dashboard view showing dual map displays with different indicators. The interface includes: (A) indicator selection menu, (B) interactive maps with editing options, (C) legend information, and (D) spatial aggregation controls. source: Pluto-Kossakowska et al., 2022 from Eindhoven in Cijfers.
Available online: https://eindhoven.incijfers.nl/jive

Technical and Methodological Aspects:

- Types of Data Used: Eindhoven in Cijfers leverages a diverse range of data sources. It functions as an open data portal, publishing its own municipal data, including information derived from surveys of residents. The platform also integrates data from external entities, such as central statistical offices and other institutions; for instance, some indicators are presented via the Netherlands Statistical Office website. Additionally, it incorporates real-time data from meters and sensors installed across the city, such as fine dust monitoring. All datasets are typically accompanied by metadata, detailing aspects like modification date, accuracy, collection method, and license.

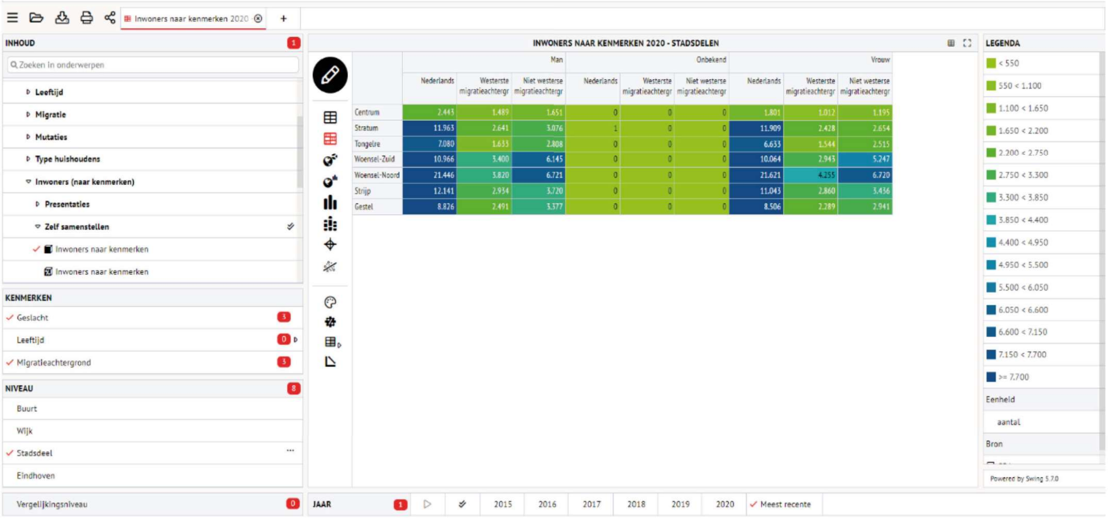
- Georeferencing of Indicators: Indicators on Eindhoven in Cijfers are consistently georeferenced to various spatial aggregation levels, including the entire city, districts, or 117 distinct neighborhood areas. This granular detail allows for precise assessment of specific urban areas. The data are often visualized on choropleth maps, with OpenStreetMap (OSM) serving as the topographic base layer. Users are also provided with tools to define and group existing areas to create custom spatial units for analysis and visualization.

- Categories of Indicators Monitored: The platform's main dashboard presents over 200 different indicators, categorized into 12 thematic groups. These categories broadly encompass aspects of urban quality of life and sustainable development, including Demographics, Economy, Health and well-being, Transport, Environment, Energy, Finance, Assets, Housing, Sport, recreation, culture, Safety, and Education. A specialized dashboard was also developed to monitor quality of life indicators specifically in the context of the COVID-19 pandemic, grouping them into economy, society, order and security, and environment.

- References to SDGs or 2030 Agenda: While the source discusses the broader importance of urban resilience and the need for timely assessment of progress towards policies like the Sustainable Development Goals (SDGs) in a post-pandemic era, it does not explicitly state that the Eindhoven in Cijfers dashboard directly reports against or references specific 2030 Agenda targets within its interface. However, the platform's overarching objective to monitor "sustainable urban development" inherently aligns with the principles of the SDGs.

- Interactivity and Visualization Methods: Eindhoven in Cijfers offers a highly interactive user experience. Users can customize visualizations by selecting classes, color schemes, labels, and cartographic layers, and can define specific time windows for data display (e.g., from 2005 to 2020). Data can be presented in tabular form, as choropleth maps, or as various types of charts. The platform supports multidimensional themes, allowing users to break down data by attributes like age, gender, or marital status within a theme like "Residents". Advanced features include tools for comparing multiple features, tracking changes over time, and even creating custom metrics and indicators using functionalities like percentage comparisons, growth rates, or Z-scores. Users can also generate and download infographics, and the platform provides options to download data in multiple formats including XLS, MP4, CSV, PDF, DOC, PPT, and XML.

- Software and Technology Used: The platform is built using SWING Mosaic, Viewer, and Studio software and tools, designed for managing, analyzing, presenting, and sharing statistical and geographical information. These commercial IT tools provide functionalities such as user authorization, data security, report generation, and multi-language versions. The portal is equipped with general modules that enable users to freely compose, display, and analyze datasets, and it offers an API module/console for advanced users. The system's "abundant tools" and "clear layout" are designed for ease of use, despite its complex functionalities, making it accessible even to non-specialist users.



INWONERS NAAR KENMERKEN 2020 - STADSDELEN

	Man			Onbekend			Vrouw		
	Nederlands	Westerste migratieachtergr	Niet westerse migratieachtergr	Nederlands	Westerste migratieachtergr	Niet westerse migratieachtergr	Nederlands	Westerste migratieachtergr	Niet westerse migratieachtergr
Centrum	2.443	1.489	1.651	0	0	0	1.801	1.012	1.195
Stratum	11.963	2.641	3.076	1	0	0	11.909	2.428	2.654
Tongelre	7.080	1.633	2.808	0	0	0	6.633	1.544	2.515
Woensel-Zuid	10.966	3.400	6.145	0	0	0	10.064	2.943	5.247
Woensel-Noord	21.446	3.820	6.721	0	0	0	21.621	4.255	6.720
Strijp	12.141	2.934	3.720	0	0	0	11.043	2.860	3.436
Gestel	8.826	2.491	3.377	0	0	0	8.506	2.289	2.941

Figure 6: This panel displays demographic data about residents across multiple dimensions, showing tabular data organized with gender and migration status as column categories. source: Pluto-Kossakowska et al., 2022 from Eindhoven in Cijfers.
Available online: https://eindhoven.incijfers.nl/jive

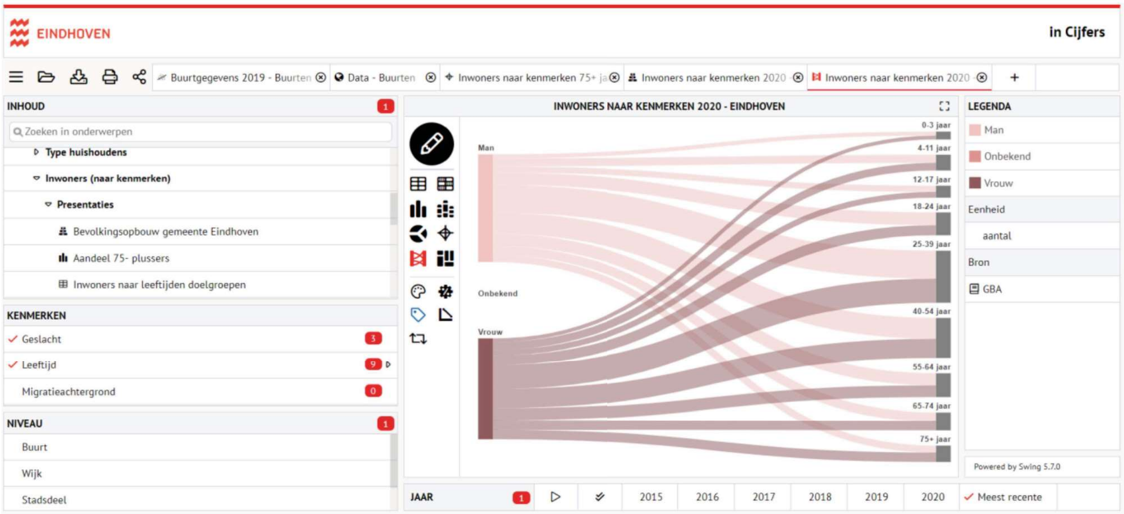


Figure 7: A graph depicting the city's population structure, showing the distribution of inhabitants by age, separated into women and men categories. source: Pluto-Kossakowska et al., 2022 from Eindhoven in Cijfers.
Available online: https://eindhoven.incijfers.nl/jive

Main Strengths:

- Comprehensive Data and Tools: Eindhoven in Cijfers stands out for its large and balanced number of indicators and its extensive suite of visualization and data analysis tools. It supports various data types, including open data, data from central statistical offices, surveys, and real-time data from city sensors.

- High Interactivity and Customization: Users can customize visualizations by selecting classes, color schemes, labels, and layers, and define specific time windows for data display, facilitating in-depth analysis. The platform offers multiple presentation formats including tables, choropleth maps (using OpenStreetMap as a base), and various charts, alongside advanced features for creating custom metrics like Z-scores or growth rates.

- Granular Spatial Analysis: Indicators are precisely georeferenced to city, district, or 117 different neighborhood areas, allowing for detailed spatial assessment and comparison across various urban units.

- Adaptive Response: The platform demonstrated its adaptability by developing a special dashboard to monitor quality of life indicators in the context of the COVID-19 pandemic, providing insights into its socio-economic and environmental impacts and supporting timely policy adjustments.

- Open Data Policy: The city office openly publishes its data, making it available for reuse and supporting transparency and participatory governance, aligning with initiatives like the EU's Open Data Directive.

Limitations or Challenges:

- Complexity for Non-Specialists: Despite efforts to maintain a clear layout, the platform's abundance of tools means it is considered "rather more suitable for IT or GIS specialists" than for general users, potentially limiting its accessibility for the average citizen.

- Data Interpretation and Metadata: While metadata is generally provided, the source notes that scales of values are "not always provided," which can make interpretation more difficult, and highlights a general challenge that "without metadata, the use of datasets is limited".

- General Accessibility Features: The review points out a general lack of "specialized studies for people with vision difficulties" and emphasizes the importance of providing accessibility features for dashboards.

- Economic: The use of commercial IT tools like SWING Mosaic, Viewer, and Studio, while offering robust functionalities and technical support, implies a potential economic investment that may not be feasible for all municipalities.

The platform is designed to evaluate the effects of different city policies over time by using a circular model for presenting results, aiming to "calibrate their application in the future". It serves as a communication channel for reporting and providing insight into the implementation of adopted urban plans and strategies, indicating its role in evidence-based decision-making.

The specific COVID-19 dashboard was also developed to “help timely policy adjustments” in response to the pandemic’s impact.

Eindhoven in Cijfers is presented as a “target model” for mature and extended urban dashboards, suggesting it is an aspiration for other cities rather than a starting point. Its underlying technology, SWING Mosaic, is used by public institutions in Europe, indicating that the technical framework is available for others. Furthermore, the dashboard’s design for the Netherlands Statistical Office, expected to be used by other Dutch cities for comparisons, directly supports its replicability and potential for broader application.

The research recommends “complex use” dashboards like Eindhoven’s for specialists, contrasting with simpler models for general residents, implying that successful replication requires considering the target user group and adapting the level of complexity.

2.1.2 Dublin Dashboard

Research paper: **Dashboard as a Platform for Community Engagement in a City Development—A Review of Techniques, Tools and Methods**

Authors: Joanna Pluto-Kossakowska, Anna Fijałkowska and Sylwia Krzysztofowicz, Małgorzata Denis, Joanna Jaroszewicz

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The Dublin Dashboard, formerly available at www.dublindashboard.ie, represented a strategic collaboration between Dublin City Council, Maynooth University, and various supporting organizations. It should be noted that this platform ceased operations in January 2022.

The primary function of the Dublin Dashboard was to serve as a civic engagement platform for urban development and a vital communication channel between municipal authorities and residents. Its fundamental aim was to quantify and visualize quality-of-life metrics in Dublin, providing citizens with access to comprehensive urban data. This approach aligns with the established purpose of urban dashboards, which present visualizations of a city’s operational metrics, structural elements, patterns, and developmental trajectories through analytical visualization tools.

he system was engineered to enhance service management efficiency, support evidence-driven policy formulation, and facilitate citizen empowerment by delivering information that encourages participation, enhances living standards, and stimulates entrepreneurial activity. Specifically, it rendered sophisticated demographic and economic data analyses in accessible formats.

While characterized as employing “simplified visualization techniques,” the platform featured interactive maps and graphs, and incorporated “stories” (multimedia narratives combining text, interactive cartography, and visual elements) to showcase significant initiatives and projects, thereby facilitating civic dialogue. Particularly noteworthy was its emphasis on housing history and the integration of real-time sensor-based indicators.

The spatial coverage of the Dublin Dashboard encompassed the entirety of Dublin, Ireland’s capital and largest urban center. The dashboard presented 21 indicators at the city-wide level, without subdivision into neighborhood-level metrics. Nevertheless, it delivered straightforward, comprehensible visualizations and presented longitudinal indicator data, designed to be readily accessible and informative for the general public.

Contemporary cities confront challenges including insufficient green spaces and spatial disorganization, issues that became particularly apparent during the COVID-19 pandemic. Addressing these concerns necessitated increasing recognition of the importance of civic participation in shaping urban environments. The evolution of smart city frameworks, particularly versions 3.0 and 4.0, emphasized the essential role of municipal governments in enabling residents to co-create their urban spaces through technological innovation and participatory governance. The dashboard was designed to address information asymmetries, providing residents with comprehensible data regarding their city's assets and limitations, thereby enhancing transparency, civic engagement, and participation in urban policy formulation. The imperative for transparent governance and accountability underscored the need for data-driven platforms such as the Dublin Dashboard.

Regarding data sources utilized, the Dublin Dashboard notably incorporated metrics from urban monitoring sensors, including those tracking vehicular traffic volume throughout Dublin. Additionally, it presented refined demographic and economic analytical results. While broader discourse in the source material emphasizes the increasing significance of open government data (OGD) and advocates for its dissemination by municipalities, with Dublin maintaining a separate "Dublin Local Authorities dashboard with open data sets," the sources do not explicitly clarify whether the Dublin Dashboard itself directly integrated all its data from open repositories as primary inputs, beyond sensor-derived information and pre-processed demographic/economic statistics. Data sources typically encompassed municipal records, resident surveys, national statistical offices, and various institutional databases.

The spatial referencing of indicators on the Dublin Dashboard operated primarily at the city-wide scale. Its 21 indicators were aggregated for the entire metropolitan area, without disaggregation into more detailed spatial units such as neighborhoods or districts.
Regarding indicator categories monitored, the Dublin Dashboard organized its 21 indicators across six thematic domains. Specific categories included Demographics (4 indicators), Economy (7 indicators), Transport (3 indicators), Housing (4 indicators), and Education (1 indicator). A prominent focus of the dashboard was the historical development of housing, while environmental metrics, such as noise level measurements, were also intended for inclusion, though temporarily unavailable during certain periods.

While the source materials extensively address the significance of sustainable development principles, quality-of-life metrics, and smart city frameworks (Smart City 3.0 and 4.0), and reference international standards such as ISO 37120 and ISO 37122 for sustainable and smart city indicators, there exists no explicit indication in the provided documentation that the Dublin Dashboard specifically referenced or aligned its metrics with the United Nations Sustainable Development Goals (SDGs) or specific 2030 Agenda targets. The documentation contextualizes the dashboard within the broader framework of enhancing quality of life and facilitating community engagement in urban development.

The platform's interactive features and visualization methodologies were characterized as employing "simplified visualization techniques," yet they facilitated user interaction with cartographic and graphical elements. A distinctive feature was the implementation of "stories," comprising integrated narratives with interactive maps and multimedia components (including photographic and video content) to highlight significant initiatives and foster dialogue. The dashboard prioritized clarity and simplicity in its graphical representations and presented indicators from a longitudinal perspective to enhance accessibility and relevance for a general audience.

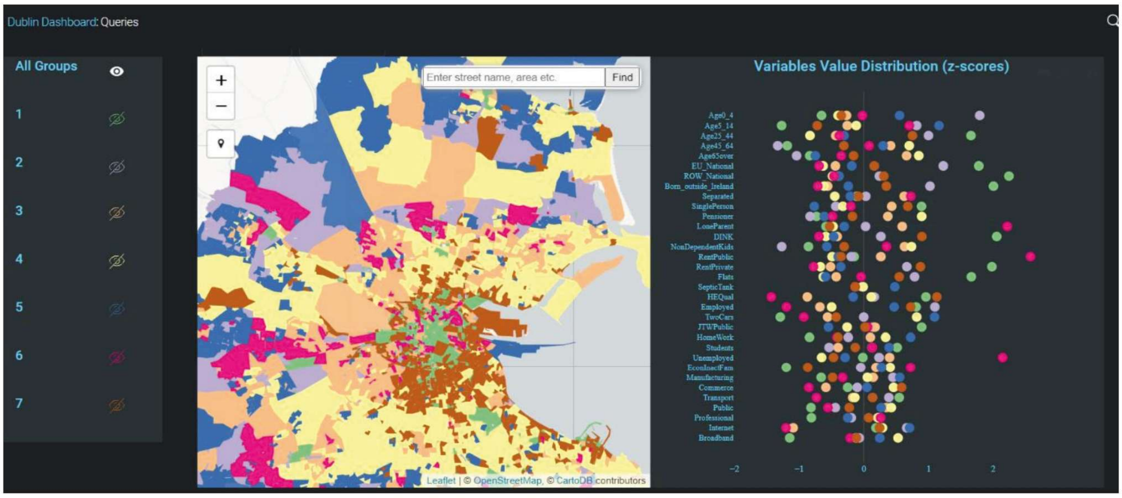


Figure 8: A visual representation showing how complex dataset processing systems work behind the seemingly simple dashboard visualizations. source: Pluto-Kossakowska et al., 2022 from DublinDashboard.
Available online: https://www.dublindashboard.ie/

Regarding technological infrastructure, the Dublin Dashboard specifically utilized ESRI ArcGIS Story Maps, a specialized tool designed for creating engaging narratives through interactive cartography and multimedia integration. While the specific database architecture or comprehensive web mapping infrastructure is not detailed, the implementation of ArcGIS Story Maps implies underlying Geographic Information System (GIS) and web cartography capabilities. The documentation also indicates that despite its simplified visualizations, they were supported by sophisticated mechanisms for data acquisition, processing, analysis, and visualization.

The dashboard exemplifies a “simplified implementation” model, recommended as an initial approach for municipalities seeking to enhance resident engagement.
The Dublin Dashboard’s contribution to urban sustainability monitoring primarily manifested through its function as a civic engagement platform and effective communication mechanism for urban development and quality-of-life initiatives. It aimed to quantify and present data to inform residents about urban parameters, thereby enhancing transparency and civic awareness. By presenting complex demographic and economic analyses in accessible formats, it sought to empower citizens for participatory decision-making and promote enhanced quality of life. The incorporation of a focused examination of housing history and integration of sensor-derived indicators such as traffic volumes demonstrated a commitment to providing relevant urban insights.

Key advantages of the Dublin Dashboard included:

- Clarity and simplicity in data visualization, engineered for optimal comprehension by the general public.

- Interactive visualization tools, including maps and graphs that facilitated user engagement.

- Innovative implementation of “stories”, integrating text, interactive cartography, and multimedia to present significant initiatives and stimulate dialogue, rendering complex information more engaging than conventional reports.

- Presentation of indicators with longitudinal context, providing essential perspective for trend analysis.

- Foundation in sophisticated data processing architecture, ensuring that even simplified visualizations were supported by robust data management protocols.

- Implementation of ESRI ArcGIS Story Maps, a specialized tool for creating compelling geographic narratives.

- Despite its strengths, the Dublin Dashboard encountered several limitations and challenges:

- Technical issues related to data reliability and accessibility were evident; for instance, environmental metrics such as noise measurements were temporarily inaccessible. This highlights the necessity for consistent updates and reliable data sources.

- It featured a relatively modest indicator set (21) across only six thematic categories, substantially fewer compared to more comprehensive platforms such as New York's (346 indicators).

Indicators were aggregated at the city-wide level exclusively, lacking finer spatial resolution at neighborhood or district levels, which constrains detailed local analysis.

While promoting civic awareness, the documentation does not provide specific details regarding accessibility features for users with disabilities, though this represents a standard recommendation for such platforms.

Regarding operational sustainability, the termination of the platform in January 2022 suggests potential long-term resource constraints or strategic realignments, although specific factors contributing to its discontinuation are not detailed in the available documentation.

While the platform was designed to facilitate evidence-based policy development by city administrators and enhance citizen participation, specific examples of policy modifications directly attributable to insights derived from the Dublin Dashboard are not provided. Its primary function appears to have been as an information dissemination and communication tool to support such processes rather than to demonstrate direct causal policy interventions.

Nevertheless, the Dublin Dashboard's approach demonstrates significant transferability to other urban contexts, particularly for municipalities seeking a foundational model. It is explicitly proposed as an "initial implementation model" for simpler solutions in other cities. Its emphasis on clear visualizations and accessible interactive content positions it as an exemplary model for municipalities aiming to foster civic awareness and interest in urban policies without necessitating sophisticated analytical tools for the public.

2.1.3 DATA2GO.NYC

Research paper: **Dashboard as a Platform for Community Engagement in a City Development—A Review of Techniques, Tools and Methods**

Authors: Joanna Pluto-Kossakowska, Anna Fijałkowska and Sylwia Krzysztofowicz, Małgorzata Denis, Joanna Jaroszewicz

Published in: *Sustainability*, *14*(17)

Year: 2022

The DATA2GO.NYC platform serves as a robust web-based resource delivering comprehensive data and insights into quality of life metrics across New York City.
The ecosystem includes complementary dashboards such as OurHome.NYC, which specializes in social housing data, and DATA2GOHEALTH.NYC, which focuses on health indicators, both operating within the New York City framework.

DATA2GO.NYC primarily functions to aggregate and present data on essential factors affecting New Yorkers' quality of life. The platform aims to facilitate analysis of resident well-being throughout the city. As an interactive dashboard, it effectively bridges communication between municipal authorities and residents, encouraging civic participation in urban improvement initiatives. The platform offers functional interfaces for both general users and specialists, with the latter benefiting from sophisticated data analysis capabilities, information retrieval, report generation, and results sharing. Users can access values for more than 300 indicators at multiple geographic levels (districts, census tracts) and conduct comparative analyses between selected areas. A notable feature includes the ability to examine correlations between distinct indicators, such as life expectancy and educational attainment. This functionality enables multidimensional analysis of complex urban dynamics. The platform also provides dedicated focus on key domains including health and social housing.

DATA2GO.NYC maintains an urban geographical focus, specifically addressing New York City, USA. The platform presents highly localized data, enabling analysis across various geographic scales, from entire districts to individual census tracts. This granular approach facilitates nuanced understanding of quality of life variations throughout different neighborhoods.
Modern urban design seeks to create environments that promote public health, address environmental challenges such as insufficient green space or disorganized development, and encourage sustainable living practices. For effective civic participation in urban improvement and quality of life enhancement, residents require accessible information regarding municipal strengths and challenges in user-friendly, interpretable formats. Dashboards represent effective tools for this purpose, functioning as platforms for dialogue and public information. The evolution toward "Smart City 3.0" and "Smart City 4.0" models further emphasizes resident involvement in collaborative city development, requiring municipal authorities to leverage modern technologies for urban management. DATA2GO.NYC, with its extensive indicator collection and adaptable presentation options, directly addresses these needs by enhancing data accessibility, promoting transparency and enabling participatory governance through evidence-based civic decision-making.

The platform incorporates data from multiple sources, including municipal datasets, resident surveys, official statistical agencies, and various institutions. While documentation references sensor and meter data for urban dashboards generally, specific to DATA2GO.NYC, it identifies archived information. The platform typically presents processed information converted into specific indicators rather than raw datasets.

DATA2GO.NYC georeferences indicators to enable detailed spatial analysis. Users can examine indicator values across multiple geographic scales, specifically within districts and census tracts throughout New York City. This functionality allows comparative analysis between selected areas, particularly between neighborhoods. Correlation analyses can be performed across various city districts.

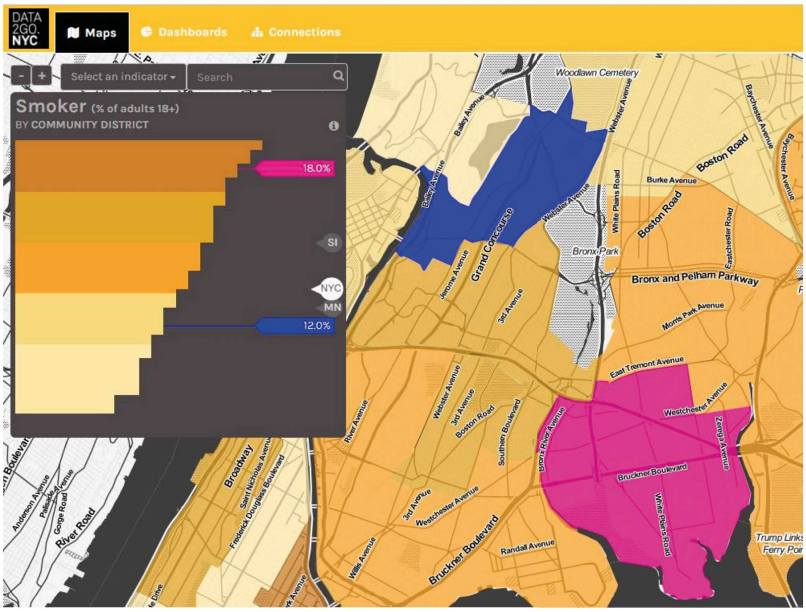
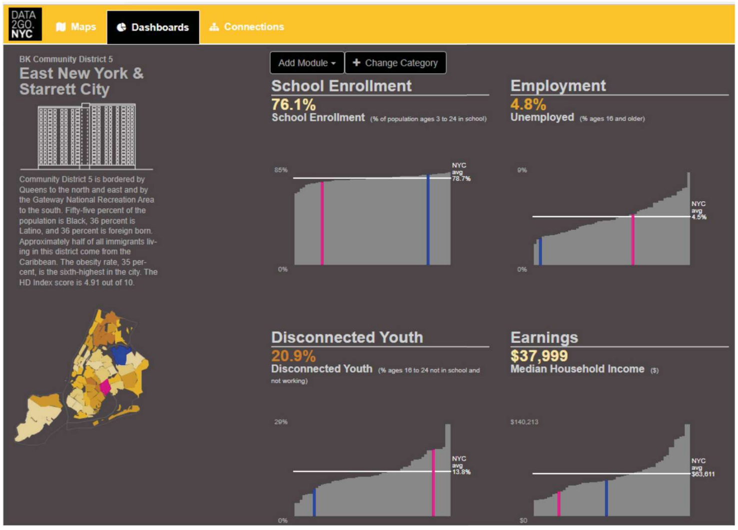


Figure 9: This visualization allows comparison of indicator values between two selected geographic areas within New York City. source: Pluto-Kossakowska et al., 2022 from DATA2GO.NYC.
Available online: https://data2go.nyc/map/



BK Community District 5
East New York & Starrett City

Community District 5 is bordered by Queens to the north and east and by the Gateway National Recreation Area to the south. Fifty-five percent of the population is Black, 36 percent is Latino, and 36 percent is foreign born. Approximately half of all immigrants living in this district come from the Caribbean. The obesity rate, 35 percent, is the sixth-highest in the city. The HD Index score is 4.91 out of 10.

School Enrollment
76.1%
School Enrollment (% of population ages 3 to 24 in school)

Employment
4.8%
Unemployed (% ages 16 and older)

Disconnected Youth
20.9%
Disconnected Youth (% ages 16 to 24 not in school and not working)

Earnings
$37,999
Median Household Income ($)

Figure 10: Visualization comparing demographic metrics across two New York City districts. source: Pluto-Kossakowska et al., 2022 from DATA2GO.NYC.
Available online: https://data2go.nyc/map/

DATA2GO.NYC presents an extensive indicator collection, comprising 346 metrics across diverse categories, positioning it among the most comprehensive dashboards evaluated. The platform employs a “cross-sectional approach to indicators”. New York City demonstrates particular strength in “demographics” with over 110 indicators. Additional significant categories include “health and well-being” (63 indicators), identified as a priority focus, and “economy” (60 indicators). The dashboard further incorporates metrics for “finance, assets” (30), “housing” (26), “safety” (24), “education” (18), and “environment, energy” (9). The platform maintains affiliated portals including OurHome.NYC for social housing and DATA2GOHEALTH.NYC for health information, indicating thematic specialization in data presentation.

DATA2GO.NYC functions as a dashboard utilizing choropleth maps and interactive charts. It offers adaptable presentation options and enables users to create customized dashboards. Key interactive features include:

- Comparison tools: Users can analyze values for selected indicators between specific areas, with results displayed as bar charts contextualizing them against overall values across all evaluated areas.
- Correlation analysis: The platform enables assessment of relationships between indicator pairs from its extensive catalog, presenting Pearson correlation coefficients. This functionality integrates with district boundary visualizations, facilitating neighborhood-level comparisons.
- Data management: Users benefit from data filtering capabilities, aggregation level adjustments, and benchmarking functions.
- Customizable visualizations: The platform allows visualization adaptation to specific requirements, including chart type modifications and map-based representations.
- Data Download: Users can export datasets for independent analysis. The dashboard features a “modern interface” and comprehensive functionality, making it particularly valuable for professional users.

The DATA2GO.NYC dashboard represents a significant case study in urban sustainability and quality of life monitoring, particularly for major metropolitan areas. Its development reflects contemporary urban planning philosophy centered on resident needs and well-being, providing insights into municipal strengths and challenges to facilitate active civic participation in improving urban environments. As a web-based solution, it functions as an essential communication and information resource between municipal authorities and residents, enabling informed dialogue and decision-making.

Main Strengths:

- Comprehensive Data Coverage: DATA2GO.NYC distinguishes itself through extensive indicator presentation, encompassing 346 metrics across multiple domains, positioning it among the most comprehensive dashboards evaluated. It demonstrates particular strength in “demographics” with over 110 indicators while also featuring substantial “health and well-being” (63 indicators) and “economy” (60 indicators) sections.
- Advanced Analytical Capabilities: The platform enables users, particularly specialists, to

analyze data at detailed geographic levels, including districts and census tracts. Users can conduct comparative analyses between selected areas and perform correlation assessments between different indicators, such as life expectancy and educational attainment. This “cross-sectional approach to indicators” provides multidimensional insights into urban dynamics.

- Interactivity and Customization: The platform offers adaptable presentation methods, including choropleth maps and interactive charts, and enables users to create personalized dashboards. This flexibility enhances user engagement and facilitates customized data exploration.
- Transparency and Participatory Governance: By providing extensive urban data access, DATA2GO.NYC supports participatory governance principles, enabling residents to make evidence-based decisions regarding their communities and promoting transparency in municipal operations.

Limitations and Challenges:

- Target Audience Considerations: While powerful, the platform’s advanced functionality and extensive indicator catalog suggest it is “more appropriate for technical and GIS specialists” than general users, potentially limiting broader public accessibility.
- Data Currency: Not all DATA2GO.NYC information represents current conditions. For instance, certain unemployment data cited covers 2014-2018, while public housing waiting list information dates to 2015, indicating update frequency and consistency may vary across indicators. The documentation notes limited information regarding update schedules across urban dashboards generally.
- Metadata Information: Similar to many dashboards, DATA2GO.NYC may present challenges regarding metadata completeness, which remains essential for accurate interpretation and analysis.
- Economic and Accessibility Factors: Documentation does not address operational costs associated with maintaining this sophisticated platform. Additionally, it does not specify whether DATA2GO.NYC incorporates accessibility features (such as high-contrast options for visually impaired users), which remain essential for inclusive information access.

The platform aims to enhance active participation and involvement in decision-making processes. DATA2GO.NYC represents a “complex use” dashboard model, appropriate as a “target framework” for municipalities pursuing advanced data presentation and analysis capabilities. While its comprehensive nature and sophisticated features make it an exemplary model, documentation suggests fully replicating its complexity may present challenges for all urban contexts, particularly for municipalities with limited resources or less specialized user populations. Simpler dashboard implementations are recommended as initial approaches for cities with different requirements or capabilities.

2.1.4 Brampton, Canada

Research paper: **Dashboard as a Platform for Community Engagement in a City Development—A Review of Techniques, Tools and Methods**

Authors: Joanna Pluto-Kossakowska, Anna Fijałkowska and Sylwia Krzysztofowicz, Małgorzata Denis, Joanna Jaroszewicz

Published in: *Sustainability*, *14*(17)

Year: 2022

Brampton, Canada, implements an integrated network of digital platforms and dashboards designed to facilitate stakeholder engagement, enhance institutional transparency, and advance urban development and administration. These platforms function as essential communication channels that provide citizens with readily accessible and comprehensible information about their municipality.

Core Platforms and Their Primary Functions:

- Brampton GeoHub: This comprehensive platform functions as a centralized repository for data dissemination and analysis pertaining to municipal operations. It incorporates analytical tools to facilitate data interpretation and features “stories” – engaging narratives that integrate text, interactive cartography, and multimedia elements to convey information effectively.

- Brampton City Dashboard: This monitoring interface is dedicated to illustrating the municipality’s advancement toward established objectives across various urban sectors. It utilizes streamlined, informative graphics to indicate progress toward specific targets. According to assessment, it presents 56 distinct metrics, with an emphasis on accessibility and contextual explanation for each indicator.

- Business Directory Brampton: This specialized portal enables users to identify local commercial entities through multiple parameters including business classification, corporate designation, service description, and operational scale (workforce size or facility dimensions).

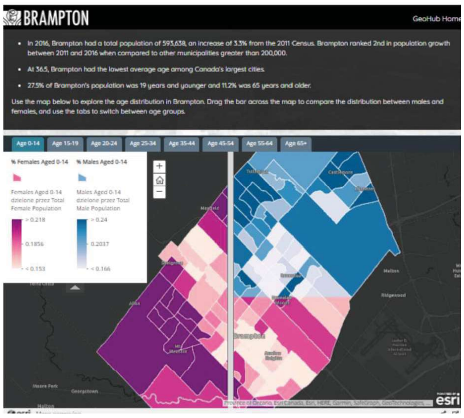
- Planning Viewer Brampton portal: This specialized application focuses on urban development and construction inquiries. It facilitates searches for construction permits through multiple criteria and enables users to identify planned capital investments within specified perimeters around selected locations, with proximity zones extending to 2000 meters.

- My Brampton portal: This platform delivers precision-targeted local information. Users may select specific property parcels to generate comprehensive reports detailing assigned municipal representatives, and identifying the five nearest recreational spaces, educational institutions, and commercial establishments with precise distance measurements, alongside zoning classification information.

- Park and Rec Locator app: This application enables users to import proprietary geospatial information from diverse sources, including ArcGIS server, OGC services, and standard file formats such as CSV, GeoJSON, and SHP.

- Brampton's Census Profile: This specialized dashboard presents demographic data from the 2016 national census, compiled by Statistics Canada. It employs ESRI technology for data visualization, featuring demographic metrics including age distribution, gender demographics, and educational attainment.

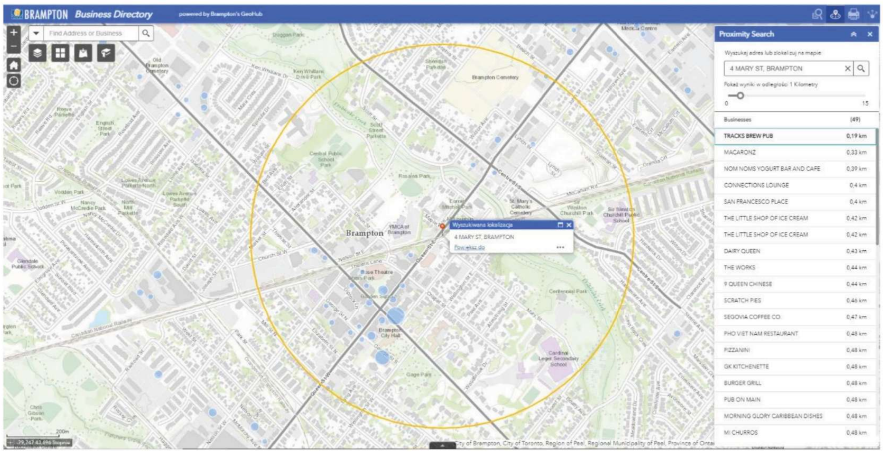
The principal geographic scope of Brampton's information systems encompasses the municipal jurisdiction, providing metrics applicable across the entire city. However, several specialized applications, including the My Brampton portal and Planning Viewer, deliver highly specific, location-based information based on precise addresses, cadastral identifications, or defined proximity parameters, addressing neighborhood-specific information requirements.



- In 2016, Brampton had a total population of 593,638, an increase of 3.3% from the 2011 Census. Brampton ranked 2nd in population growth between 2011 and 2016 when compared to other municipalities greater than 200,000.
- At 36.5, Brampton had the lowest average age among Canada's largest cities.
- 27.5% of Brampton's population was 19 years and younger and 11.2% was 65 years and older.

Use the map below to explore the age distribution in Brampton. Drag the bar across the map to compare the distribution between males and females, and use the tabs to switch between age groups.

Figure 11: A visualization of demographic indicators including age distribution, gender breakdown, and educational attainment data presented through ESRI's visualization technology in the Brampton Census Profile. source: Pluto-Kossakowska et al., 2022 from CensusofPopulation.
Available online: https://www12.statcan.gc.ca/census-recensement/index-eng.cfm



Wyszukaj adres lub zlokalizuj na mapie

4 MARY ST, BRAMPTON

Pokaż wyniki w odległości 1 Kilometry

Businesses	(49)
TRACKS BREW PUB	0,19 km
MACARONZ	0,33 km
NOM NOMS YOGURT BAR AND CAFE	0,39 km
CONNECTIONS LOUNGE	0,4 km
SAN FRANCESCO PLACE	0,4 km
THE LITTLE SHOP OF ICE CREAM	0,42 km
THE LITTLE SHOP OF ICE CREAM	0,42 km
DAIRY QUEEN	0,43 km
THE WORKS	0,44 km
9 QUEEN CHINESE	0,44 km
SCRATCH PIES	0,46 km
SEGOVIA COFFEE CO.	0,47 km
PHO VIET NAM RESTAURANT	0,48 km
PIZZANINI	0,48 km
GK KITCHENETTE	0,48 km
BURGER GRILL	0,48 km
PUB ON MAIN	0,48 km
MORNING GLORY CARIBBEAN DISHES	0,48 km
MI CHURROS	0,48 km

Figure 12: Locate entities within a defined circular boundary from a user-specified point source: Pluto-Kossakowska et al., 2022 from Business Directory.
Available online: https://brampton.maps.arcgis.com/apps/webappviewer/index.html?id=3d7354f336cf4589a18b94816cdbfae4

The implementation of these platforms in Brampton reflects contemporary urban planning principles that prioritize resident-centered design and the significance of public participation in community development. The fundamental challenge addressed is ensuring citizens have convenient access to municipal data and insights regarding their community's assets and limitations. By delivering information in an accessible and interpretable format, these platforms aim to promote collaborative governance, enabling residents to make informed decisions and actively contribute to civic affairs and community initiatives. These systems represent essential infrastructure for smart city implementation, benefiting both municipal administrators and residents by providing actionable information to enhance quality of life and encourage civic participation. The substantial public utilization, evidenced by approximately 7,000 monthly platform visits, demonstrates significant demand for these municipal resources.

The municipality's web portals are typically developed using enterprise-grade software solutions, with ESRI applications such as ArcGIS Dashboards and ArcGIS Story Maps being predominantly utilized. Brampton's Census Profile specifically leverages ESRI technology for data visualization. The Park and Rec Locator app supports data from ArcGIS servers, indicating reliance on the ESRI ecosystem. The 2016 census data presented in Brampton's Census Profile was compiled by Statistics Canada, a federal statistical agency. This implementation approach represents an integration of commercial software platforms, municipal administration, and federal data resources.

Brampton's platforms incorporate diverse data types:

- Municipally-generated information from various departments and operational functions.
- Federal census statistics, specifically from Statistics Canada, for demographic analysis.
- Commercial directory information including business profiles and geographic coordinates.
- Construction permit records and capital investment projections.
- Property parcel information and proximity data for community amenities.
- The Park and Rec Locator app's capacity to incorporate user-supplied data from ArcGIS server, OGC services (WMS, WMTS, WFS), CSV, GeoRSS, KLM, SHP, and GeoJSON files demonstrates extensive compatibility with diverse geospatial data formats. Indicators incorporate geospatial references to enable location-specific insights. This functionality operates at the municipal level for general metrics, or more precisely by property parcels, designated locations (with proximity parameters), or specific zones for functions such as business identification or planning inquiries. Distance calculations, for instance, follow public thoroughfare networks.

The 56 indicators on Brampton City Dashboard encompass various aspects of urban administration. These include demographics (2 indicators); economy (8 indicators); health and well-being (4 indicators); transport (4 indicators); environment, energy (3 indicators); finance, assets (18 indicators); housing (5 indicators); sport, recreation, culture (4 indicators); safety (8 indicators). Notably, education has 0 indicators documented.

Brampton is acknowledged for conforming to ISO 37120, an international standard for "Sustainable Cities and Communities—Indicators for City Services and Quality of Life". This alignment establishes a connection between Brampton's monitoring initiatives and broader sustainability objectives and the principles underlying the 2030 Agenda and Sustainable Development Goals (SDGs), which emphasize quality of life and sustainable urban development. The “Sustainable Development Goals Dashboard” is also referenced in discussions of systems presenting progress toward adopted objectives.

Brampton’s platforms prioritize accessibility and clarity, providing explanatory context for individual metrics.

- Brampton GeoHub implements “stories” which are integrated narratives combining textual content, interactive cartography, and multimedia elements.
- The Brampton City Dashboard employs streamlined visual representations to illustrate progress toward established objectives.
- Data visualization incorporates interactive graphical elements and color-graduated mapping.
- Functional tools enable information retrieval, selection, and filtration based on specific parameters.
- Users can identify objects within specified proximity parameters using distance-based filters.
- The Park and Rec Locator app provides functionality for users to incorporate proprietary data, enabling customized visualization and analysis.

Brampton’s platforms are distinguished by their accessibility and clarity of presentation, including explanatory context for individual metrics. A principal limitation identified for Brampton, indeed, is the restricted number of performance metrics for comprehensive municipal assessment. While the documentation notes a general concern regarding metadata completeness and update frequency across dashboard implementations, Brampton’s Census Profile relies on 2016 data, which may not reflect current conditions.

The assessment also identifies general challenges in dashboard implementation, including ensuring data quality and currency, providing comprehensive metadata, and developing effective spatial analysis methodologies. Accessibility features for users with disabilities are also generally underrepresented in dashboard implementations.

2.1.5 Neighborhood Indicators Project Madison, USA

Research paper: **Dashboard as a Platform for Community Engagement in a City Development—A Review of Techniques, Tools and Methods**

Authors: Joanna Pluto-Kossakowska, Anna Fijałkowska and Sylwia Krzysztofowicz, Małgorzata Denis, Joanna Jaroszewicz

Published in: *Sustainability*, *14*(17)

Year: 2022

The Neighborhood Indicators Project Madison (USA) constitutes a sophisticated dashboard platform that delivers comprehensive insights into quality of life metrics within Madison. The primary function of this initiative is to facilitate monitoring of discrete urban areas through the presentation of various indicators reflecting residents' living standards.

This analytical tool enables stakeholders to visualize and compare metrics across different geographic units within the city, enhancing understanding of localized conditions.

Developed with analytical precision, the platform provides substantive explanations regarding the significance of each indicator. Additionally, it offers data export capabilities and report generation functionality, accommodating both observational and analytical user engagement.

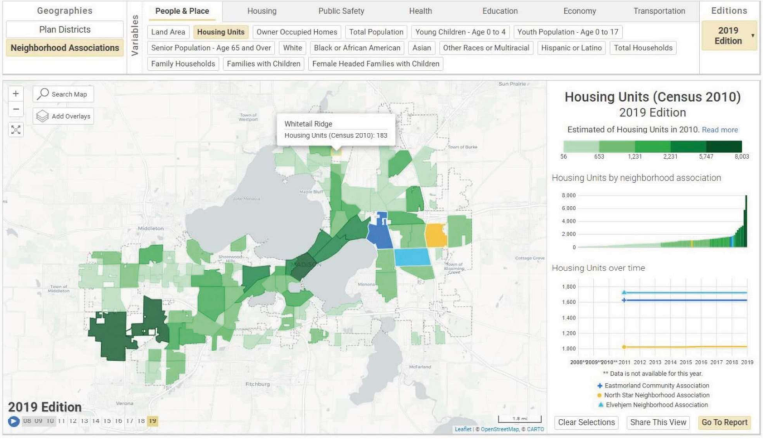
While no specific developer organization is explicitly identified in the source documentation, the platform can be accessed via https://madison.apl.wisc.edu/. The domain extension strongly indicates that the platform is affiliated with or developed by the University of Wisconsin, presumably through an academic department focusing on applied science or planning, suggesting a collaborative academic-public sector initiative.

The geographic focus of the Neighborhood Indicators Project is specifically concentrated on Madison, USA. The platform delivers granular spatial data, enabling users to conduct comparative analyses of conditions within specific "individual parts of the city," including designated Madison districts or neighborhoods. This detailed spatial disaggregation ensures the data maintains relevance and practical utility for both residents and urban planning professionals.

Dashboard interfaces are recognized as "effective mechanisms for information exchange between municipal entities and residents" by presenting data in accessible formats. The Madison dashboard's development aligns with the broader international movement toward open government data (OGD), motivated by objectives to enhance transparency, promote participatory governance, and facilitate public data utilization for societal and economic advancement.

By providing residents with access to this information, the Neighborhood Indicators Project endeavors to render them "more informed about their immediate environment, better equipped with knowledge, and capable of making evidence-based decisions."

Despite its interface being characterized as "not employing contemporary design principles," the dashboard's strength resides in its analytical capabilities and comprehensive explanations, serving as a valuable resource for both general users and specialists interested in understanding and improving Madison's urban environment.


Housing Units (Census 2010)
2019 Edition
Estimated of Housing Units in 2010. Read more

Whitetail Ridge
Housing Units (Census 2010): 183

** Data is not available for this year.

Figure 13: A color-coded map displaying household distribution patterns across different neighborhoods in Madison. source: Pluto-Kossakowska et al., 2022 from MadisonNeighborhood Indicators Project.
Available online: https://madison.apl.wisc.edu/

Regarding data sources, the dashboard likely incorporates diverse information types common among urban information systems. These typically include municipal datasets, resident survey results, statistical office information, and data from external institutions.

The indicators feature geospatial referencing to various “selected Madison districts” or “designated units” within the city, enabling localized analysis and comparative assessment. Data aggregation typically occurs at the neighborhood, district, or census tract levels. For instance, a choropleth map specifically illustrates “a comparison of household characteristics across selected Madison districts.” The platform also visualizes accessibility metrics, such as public transit stops within 15-minute walking distances, referenced to administrative boundaries.
The Madison dashboard monitors 54 distinct indicators across several key domains related to quality of life. These include: Demographics (16 indicators); Economy (3 indicators); Health and well-being (2 indicators); Transport (4 indicators); Housing (12 indicators); Safety (9 indicators); Education (8 indicators). Notably, categories such as “Environment, Energy,” “Finance, Assets,” and “Sport, recreation, culture” are not represented among Madison’s indicators, unlike some comparable urban dashboards.

Regarding interactivity and visualization, the platform utilizes a dashboard interface incorporating choropleth maps and data visualization charts to present information. It features “analytical and descriptive development,” providing substantive explanations regarding each indicator’s significance. Users possess the capability to conduct comparative analyses between citywide metrics and selected geographic units, and can export data and generate analytical reports. While its visual interface is characterized as “not employing contemporary design principles,” its strength resides in its analytical depth and comprehensive documentation. The interactive functionality of such platforms typically enables dynamic data transformation based on user-defined parameters and visualization of temporal trends, though specific documentation of Madison’s advanced features remains limited.

The Neighborhood Indicators Project Madison (USA) platform represents a dashboard that provides a relevant case study for understanding urban monitoring and sustainability initiatives. Its core function is to facilitate the monitoring of specific urban sectors by presenting diverse indicators reflecting residents’ quality of life. This directly contributes to urban sustainability monitoring by providing stakeholders with essential information regarding municipal strengths and limitations, enabling them to make evidence-based decisions and actively participate in community improvement initiatives. This aligns with contemporary urban frameworks such as the “city of well-being” and “smart city” concepts, which increasingly adopt a human-centered

methodology, prioritizing quality of life and civic engagement.
The Madison dashboard exhibits several notable strengths:

- It features analytical and descriptive development, not only presenting data but also providing substantive explanations regarding each indicator's significance. This enhances user comprehension, rendering it accessible to both specialists and general users.

- A significant functionality is its capacity to facilitate comparative analysis between citywide metrics and selected geographic units. For instance, a choropleth map illustrates "a comparison of household characteristics across selected Madison districts," enabling granular spatial analysis.

- Users can export data and generate analytical reports, promoting active engagement and independent analysis.

- The platform monitors 54 distinct indicators across significant domains, including demographics (16), economy (3), health and well-being (2), transport (4), housing (12), safety (9), and education (8). Indicators feature geospatial referencing to specific Madison districts or units, enabling localized insights.

However, the Madison case study also reveals certain limitations and challenges:

- From a technical perspective, its visual interface is characterized as "not employing contemporary design principles," and its color scheme is identified as a limitation.

- Regarding thematic scope, domains such as "Environment, Energy," "Finance, Assets," and "Sport, recreation, culture" are notably absent from Madison's indicator framework, unlike comparable urban dashboards.

- Concerning data currency, the general observation that "Most municipalities do not provide comprehensive documentation regarding update frequency" suggests a potential area for enhancement for Madison, as real-time sensor data (exemplified by Eindhoven's implementation) is not documented for Madison.

- Accessibility features for users with disabilities (particularly visually impaired individuals) are generally identified as inadequate across evaluated dashboards, suggesting this may represent a limitation for Madison as well, given the absence of documentation regarding such functionalities.

- The source materials do not provide specific information regarding financial challenges encountered during development or maintenance phases.

The transferability of the Madison dashboard to other urban contexts is substantial. The study itself utilizes Madison as an exemplar in a review of dashboards aimed at identifying "best practices" for urban development monitoring platforms. Madison is specifically recommended as a "comprehensive" dashboard model for specialists, alongside Eindhoven and New York, due to its analytical depth and detailed documentation. This suggests its approach to data presentation and analysis can serve as a framework for municipalities seeking to provide comprehensive, evidence-based insights into urban quality of life. The broader international trend toward open government data (OGD) and the increasing emphasis on civic engagement further support the transferability of such platforms.

2.1.6 Hamilton, New Zealand

Research paper: **Evaluating the 15-minute city paradigm across urban districts: A mobility-based approach in Hamilton, New Zealand**

Authors: Tianyi Wang, Yan Li , I-Ting Chuang , Weijie Qiao , Jing Jiang , Lee Beattie

Published in: *Cities*, *151*

Year: 2024

According to the research literature, Hamilton, New Zealand lacks a designated digital platform or dashboard for urban monitoring and planning communication. Instead, researchers from the University of Auckland have developed a comprehensive analytical framework to evaluate the '15-minute city' concept within Hamilton's urban environment. This framework functions as a sophisticated analytical tool that generates evidence-based insights to enhance urban planning decisions and policy development.

The framework's objectives are multifaceted:

- To evaluate the feasibility of implementing the '15-minute city' model across Hamilton's varied urban districts;

- To map accessible neighborhoods where residents can reach essential services within 5, 10, and 15-minute walking timeframes using Geographic Information System (GIS) technology;

- To examine resident movement patterns through geolocated mobile phone data, with particular focus on "inflow" and "outflow" travel metrics, to determine how residents navigate their urban environment and whether their movement aligns with localized living principles;

- To assess the compatibility of Hamilton's current urban configuration with '15-minute city' principles and to identify areas requiring improvement;

- The framework ultimately aims to provide data-driven evidence and strategic insights that can guide policy development and implementation toward creating more sustainable urban environments both in Hamilton and internationally.

The research encompasses analyses at the metropolitan scale for broader mobility trends and more granular district-level assessment focusing on four distinct urban typologies: Frankton (industrial-focused), Hamilton Central (business-oriented), Claudelands (mixed residential), and Hamilton East (historical-residential).

The driving factors that prompted the development and application of this framework stem from several key urban challenges:

- The global momentum toward sustainable urban development, which gained increased attention following the COVID-19 pandemic, highlighting vulnerabilities in conventional urban planning approaches.

- The fundamental challenge of rapid urban growth and the necessity for innovative urban reform models such as the ‘15-minute city’ to address sprawling, automobile-centric development patterns.

- Hamilton’s specific challenge of excessive automobile dependence and urban sprawl, with 66% car usage, substantially higher than New Zealand’s national average. This positions Hamilton as an ideal test case for sustainable urban development solutions.

- The framework also addresses the observation that ‘15-minute city’ implementations frequently fail to consider the specific characteristics and existing urban structures of diverse city districts, resulting in suboptimal outcomes and emphasizing the need for a tailored, context-appropriate approach.

This adaptable framework is presented as a valuable methodological resource that can be applied and tailored to various urban contexts globally, facilitating comparative studies and broadly contributing to urban sustainability research.

The methodological specifications are outlined as follows:

- Data Sources Utilized:

    - Geolocated mobile device data constitutes a primary input, acquired from Quadrant (Quadrant/Location Data) covering 2019–2022. This dataset encompasses over 9.3 million location points from 88,660 anonymized users within Hamilton, including device identifiers, temporal data, and geographic coordinates.

    - Points of Interest (POIs) data are essential for accessibility analysis. These were obtained from GEOFABRIK downloads (OpenStreetMap) and enhanced in ArcGIS Pro to incorporate parks and natural reserves. The analysis concentrates on six categories of essential amenities: grocery stores/supermarkets, educational institutions, recreational areas, healthcare facilities, dining establishments, and public transportation hubs.

    - Hamilton district planning documentation was also incorporated as a reference source.

- Spatial Analysis and Indicator Development:

    - The analysis framework employs Geographic Information System (GIS) mapping methodologies as its foundation.

    - ArcGIS Pro software, particularly its network analysis functionality, was utilized to generate isochrones or service areas around each POI. These isochrones delineate “accessible neighborhoods” by mapping areas where essential services can be reached within 5, 10, and 15-minute walking durations, corresponding to approximate distances of 400m, 800m, and 1200m.
    - Mobile device data points were structured into 100m x 100m hexagonal grid cells to maintain privacy standards and ensure sufficient data density for comprehensive analysis across Hamilton’s 110 km² area.
    - The ‘homelocator’ package in RStudio was implemented to determine the likely residential locations of mobile device users within these hexagonal grid cells.

- Key Performance Indicators:
    - Urban Accessibility Assessment: Quantified by the geographic coverage and percentage of “accessible neighborhoods” within the defined isochrones across various districts.
    - Human Mobility Analysis: Examined through several critical metrics:
        - Average Inflow Distance (AID): Measures the average travel distance of non-resident visitors to specific grid cells, indicating the attractiveness and functional diversity of an area.
        - Average Outflow Distance (AOD): Determines the average travel distance of residents from their home grid cells, reflecting their utilization of local services or tendency toward longer travel.
        - Weighted Outflow Distance (WOD): This localized measure employs an inverse distance weighting (IDW) methodology (Inverse Distance Power parameter set to 2) to prioritize shorter trips made by residents, identifying areas that support localized living patterns.

The research is fundamentally aligned with principles of sustainable urban development, it aims, in fact, to promote resilient and equitable urban environments in the post-pandemic context, reduce automobile dependency, enhance neighborhood livability, and address socio-economic inequities through improved accessibility and public transportation options. The framework’s global applicability underscores its potential to inform policy development toward achieving broader sustainability objectives internationally.

The framework incorporates GIS mapping for dynamic visualization of accessibility patterns and isochrones. Findings are presented visually through thematic maps that employ shaded zones to illustrate “accessible neighborhoods” and color-coded grid cells to represent average inflow and outflow distances, categorizing them into walkable, bicycle-friendly, and automobile-dependent ranges. Schematic illustrations are also employed to communicate the research design, POI distribution, and identified residential locations.

The integrated approach represents a data-driven, two-phase methodology combining spatial analysis and behavioral insights to identify discrepancies and opportunities for implementing the ‘15-minute city’ concept within Hamilton’s diverse urban landscape.

The key advantages of this framework include:

- Integrated Methodology: It effectively combines GIS spatial analysis to identify “accessible neighborhoods” (areas with walkable access to essential services within 5, 10, and 15 minutes) with mobility pattern analysis using geolocated mobile device data. This integration delivers both spatial and behavioral insights.

- Graduated Accessibility Analysis: The tiered approach (5, 10, 15-minute walking radii) provides a sophisticated incremental assessment of urban accessibility, highlighting varying degrees of compliance with the ‘15-minute city’ concept across different urban configurations.

- Contextual Sensitivity: The study conducts detailed analysis across four distinct urban district typologies (business-oriented, mixed residential, historical-residential, and industrial-focused), acknowledging that standardized approaches to urban planning are ineffective and that implementation success varies across urban environments. This context-aware approach ensures customized solutions that reflect unique district characteristics.

- Comprehensive Data and Analytical Tools: It utilizes extensive geolocated mobile device data (exceeding 9.3 million location points from 88,660 anonymized users) and Points of Interest (POIs) information. The application of ArcGIS Pro for network analysis (isochrones) and RStudio’s ‘homelocator’ package to determine residential locations, alongside mobility metrics such as Average Inflow Distance (AID), Average Outflow Distance (AOD), and Weighted Outflow Distance (WOD), demonstrates its sophisticated technical foundation.

Despite these strengths, the framework encounters certain limitations and challenges:

- Data Representation Issues: Mobile device data may inadequately represent certain demographic segments, particularly older populations who may be less likely to use smartphones.

- GIS Analytical Constraints: While powerful, GIS technology has inherent limitations in capturing complex socioeconomic factors that significantly influence mobility behaviors.

- Workplace Travel Omission: The study’s exclusion of employment-related travel in its primary accessibility metrics may misrepresent observed travel patterns, particularly regarding longer commutes, as employment and income substantially impact travel behavior.

- Cultural and Social Factors: The research acknowledges that established cultural preferences for automobile use in Hamilton contribute to extended travel distances, even when local amenities are accessible, indicating that proximity alone does not ensure sustainable mobility practices. It also identifies socioeconomic disparities in transportation access.

- The literature does not specify the frequency of data updates for this framework or any economic challenges associated with its implementation. As a research methodology, direct public engagement as a dashboard feature is not applicable.

The framework’s transferability represents a significant advantage. It is characterized as adaptable and readily transferable to the unique contexts of other urban environments globally. This methodology can accommodate variations in historical development patterns, cultural norms, and socioeconomic conditions, enabling comparative analysis between different urban centers and facilitating benchmarking against sustainable urban development objectives worldwide.

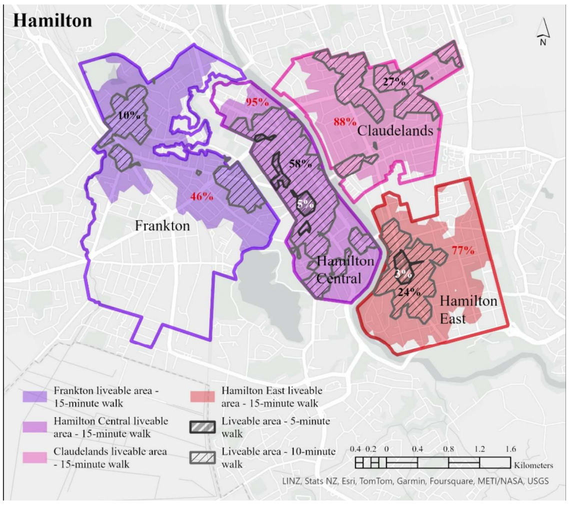


Fig. 14: Distribution of habitable regions and their proportional coverage across analyzed districts.
source: Wang et al.,2024.

2.1.7 UrbanFlow Milano

Research paper: **Visual Analytics for Sustainable Mobility: Usability Evaluation and Knowledge Acquisition for Mobility-as-a-Service (MaaS) Data Exploration**

Authors: Lorenzo Delfini, Blerina Spahiu and Giuseppe Vizzari

Published in: *Digital*, *4*(4)

Year: 2024

UrbanFlow Milano serves as a sophisticated, map-based analytical platform engineered to address specific challenges and opportunities within Milan, Italy’s urban mobility framework. This application was developed by a research team from the Department of Informatics, Systems and Communication at the University of Milano-Bicocca, with financial support provided through the MOST PNRR project under the Next Generation EU program.

The primary objective of UrbanFlow Milano is to conduct comprehensive analysis of shared mobility patterns within Milan, enabling stakeholders to effectively visualize, filter, and interact with extensive datasets to extract valuable insights. The platform is designed to enhance evidence-based decision-making processes in urban planning and transportation management.

It accommodates various analytical functions, ranging from fundamental identification and location tasks to advanced operations such as cluster identification and data filtering, through intuitive spatiotemporal visualization interfaces. The platform emphasizes user-centered design methodology, enabling stakeholders to engage meaningfully with data and extract actionable information, thereby delivering more detailed and practical insights into urban mobility trends compared to existing tools. Additionally, the system functions as an evaluation mechanism for assessing the efficacy of map-based dashboards in knowledge acquisition related to spatiotemporal data patterns.

The development of UrbanFlow Milano was initiated in response to several significant challenges and opportunities present in contemporary urban environments. Modern urban mobility networks generate substantial volumes of real-time information, creating a “big data environment” with considerable potential for transportation network optimization. However, the effective visualization of this complex and extensive data to support decision-making processes has presented significant challenges. Key issues include the challenges associated with integrating multiple data sources (including demographic information and points of interest) and addressing spatial and temporal scale considerations to create visualizations that are both comprehensive and accessible. Despite the widespread application of data visualization tools in mobility management, the development of interactive interfaces for data filtering, exploration, and insight extraction remains an active research area. Additionally, many current map-based dashboards prioritize real-time data presentation but frequently lack contextual narrative elements and encounter difficulties in implementing effective multi-perspective geovisualization. UrbanFlow Milano was created to address these limitations by providing an integrated framework incorporating multiple visualization techniques, with an emphasis on user-centric design validated through comprehensive usability assessment. The platform’s geographical focus is exclusively limited to the Milan metropolitan region, with data structured according to Nuclei di Identità Locale (NILs), which function as administrative districts comparable to neighborhoods.

The system primarily leverages big data generated by urban mobility networks, with a specific focus on shared mobility utilization. The dataset encompasses trip records for Milan throughout 2023, provided by Fluctuo, an organization specializing in shared mobility data collection from various service providers. This comprehensive dataset consolidates information from major shared mobility operators throughout the city, including attributes such as travel identification, trip start and end times and dates, vehicle classification (Moped, Car, Scooter, Bike), estimated journey duration and distance, and geographical coordinates of origin and destination points. The estimated route paths for these journeys are reconstructed using the Valhalla library’s route generation functionality. The prototype primarily focuses on geospatial information, including geographic coordinates and routes, and maintains GDPR compliance by excluding personal data.

Data indicators within UrbanFlow Milano are precisely georeferenced to the Nuclei di Identità Locale (NILs), which function as administrative districts comparable to neighborhoods within Milan. The city comprises 88 NILs of various dimensions. For each recorded journey, the corresponding NIL and its centroid coordinates are calculated based on departure and arrival points. The platform monitors mobility patterns, travel behaviors, and inter-location connectivity throughout Milan, categorizing data by transportation mode and analyzing journey volumes, durations, and distances. The Origin-Destination Flow Map, for instance, positions points representing NILs at their respective centroid locations.

UrbanFlow Milano implements user-centered design principles, delivering a highly interactive experience through multiple visualization methodologies and filtering capabilities. The application is organized into four distinct sections: Introduction, OD Flow Map, Trajectory Flow Map, and Mobility Chord Diagram. Each section features a parameter selection sidebar and a primary visualization panel.

- The OD Flow Map illustrates movement patterns between NILs utilizing points, lines, arrows, and interactive information displays showing principal origins and destinations. Users can apply filters based on incoming/outgoing connections, maximum connection quantities, and minimum opacity thresholds.

- The Trajectory Flow Map renders individual journey paths, with route lines color-coded by vehicle classification. Users can select specific NILs, filter by directional flow, customize temporal parameters, and select from various map presentation styles (dark, light, satellite, OpenStreetMap).

- The Mobility Chord Diagram represents connections between NILs using arcs whose width corresponds to journey volume. It supports filtering by vehicle type and minimum journey thresholds and provides options to toggle between graph and tabular views for precise flow quantification.

The platform accommodates both basic functions such as identification and location, and advanced analytical capabilities including cluster identification and data filtering, all through intuitive spatiotemporal visualization interfaces. It utilizes various software components and libraries for its functionality: the prototype is constructed with Streamlit, the Origin-Destination Flow Map implements Folium (with Mapbox's dark style), the Trajectory Flow Map employs Plotly for linestring data processing, and the Chord Diagram is developed using Holoviews and Bokeh for interactive functionality. The source code is accessible to the public via GitHub.

UrbanFlow Milano constitutes a highly relevant case study in the field of visual analytics for sustainable urban mobility. Its principal contribution is the development and validation of an interactive, map-based dashboard specifically engineered to enhance understanding and optimization of urban transportation networks in Milan. By facilitating the exploration and analysis of extensive real-time data from shared mobility services, UrbanFlow Milano directly supports initiatives to improve public transport quality and reduce dependency on private vehicles, addressing critical challenges for sustainable urban development. Although the documentation does not explicitly reference specific UN Sustainable Development Goals (SDGs), the project's funding through the MOST PNRR project under the Next Generation EU program aligns with broader European sustainability and digital transformation objectives. The platform's emphasis on user-centric design for "sustainable mobility" underscores its relevance to monitoring and informing sustainable urban development strategies.

The platform demonstrates several key advantages:

- User-Centered Design: UrbanFlow Milano positions users at the center of the analytical process, enabling them to actively engage with data through visualization, filtering, and interaction to uncover valuable insights. This approach enhances usability and effectiveness across diverse user scenarios.

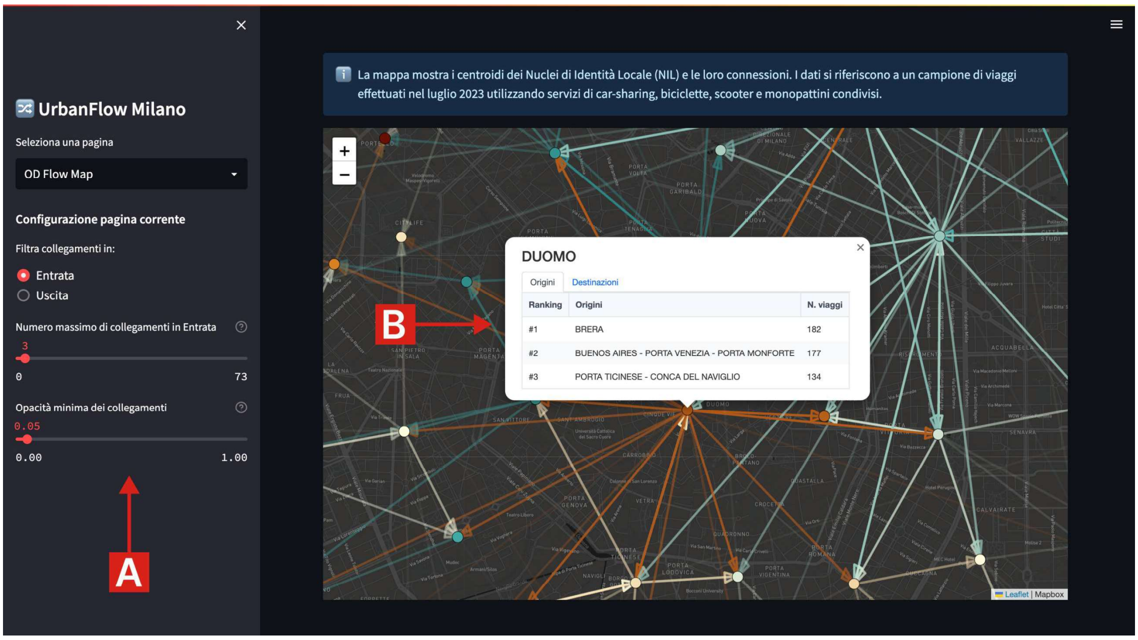
- Comprehensive Visualizations: The platform integrates multiple map-based visualization techniques, including OD Flow Maps, Trajectory Flow Maps, and Mobility Chord Diagrams, into a cohesive framework, supporting various analytical functions from basic identification to complex cluster analysis.

- Interactive Features and Customization: The dashboard provides extensive customization options, allowing users to filter data based on parameters such as directional connectivity, vehicle types, and temporal ranges, while also personalizing the map's visual presentation.

- Data-Driven Insights: The platform delivers more detailed and actionable insights into urban mobility patterns compared to previously available tools, facilitating the interpretation of travel demand and the granular impacts of events on mobility behaviors.

- Open-Source Availability: The source code is publicly accessible via GitHub, promoting transparency and enabling future development and adaptation opportunities.

Despite its strengths, UrbanFlow Milano encounters certain limitations and challenges,



Seleziona una pagina

OD Flow Map

Configurazione pagina corrente

Filtra collegamenti in:

● Entrata
○ Uscita

Numero massimo di collegamenti in Entrata: 3 (0–73)

Opacità minima dei collegamenti: 0.05 (0.00–1.00)

La mappa mostra i centroidi dei Nuclei di Identità Locale (NIL) e le loro connessioni. I dati si riferiscono a un campione di viaggi effettuati nel luglio 2023 utilizzando servizi di car-sharing, biciclette, scooter e monopattini condivisi.

DUOMO

Origini | Destinazioni

Ranking	Origini	N. viaggi
#1	BRERA	182
#2	BUENOS AIRES - PORTA VENEZIA - PORTA MONFORTE	177
#3	PORTA TICINESE - CONCA DEL NAVIGLIO	134

Fig. 15: Interactive OD Flow Map visualization: The left sidebar (A) provides filtering options for the map display. A trip ranking pop-up panel (B) becomes visible when users click on NIL centroids.
source: Delfini et al., 2024

particularly regarding usability for less experienced users. User studies identified issues where participants experienced difficulty locating specific functions, such as the legend for filtering scooter trips or the map selector in the Trajectory Map interface. The Chord Diagram presented interpretation challenges regarding arc significance due to similar color schemes and difficulties in locating the table view option, especially on smaller display screens. While the system aims to provide intuitive functionality for all users, those with limited experience may require additional support or training to fully utilize all features. The complexity of integrating diverse data sources and managing spatial and temporal scales also presents a general challenge in big data visualization, although UrbanFlow Milano attempts to address these issues. Regarding data maintenance, the prototype currently utilizes trip records for Milan throughout 2023, with no specific information provided regarding the frequency of future data updates or the economic implications associated with ongoing data acquisition from commercial providers such as Fluctuo.

While UrbanFlow Milano represents a research prototype, it demonstrates clear practical value in facilitating evidence-based decision-making for urban planning and transportation management. It serves as an effective tool for professionals conducting complex analyses such as cluster identification and data filtering, which are essential for optimizing transportation strategies. The qualitative assessment demonstrates its utility in investigating the impact of events (such as public transport disruptions) on mobility patterns at a micro-level, and the relationship between shared mobility demand and specific urban districts and points of interest. However, the documentation does not provide evidence of specific policy implementations or concrete urban planning decisions that have been directly enacted *as a result* of insights derived from the UrbanFlow Milano dashboard, as its contribution focuses on advancing user-centric visual analytics tools to *support* such decision-making processes.

The adaptability of UrbanFlow Milano to other urban contexts is substantial. The underlying technical architecture, utilizing web-based mapping applications developed with open-source libraries including Streamlit, Folium, Plotly, Holoviews, and Bokeh, offers broad transferability. The data utilized, consisting of shared mobility journey records with geospatial coordinates, is commonly available in numerous cities worldwide. While indicators are georeferenced to Milan's specific Nuclei di Identità Locale (NILs), the methodology can be readily adapted to comparable administrative or statistical divisions (such as neighborhoods, districts, or census tracts) in other urban environments. The user-centered design principles and visual analytics approach provide universal applicability for developing similar tools across diverse urban contexts.

2.1.8 Turin, Italy

Research paper: **Spatial decision support system for low-carbon sustainable cities development: An interactive storytelling dashboard for the city of Turin**

Authors: Maurizia Pignatelli, Sara Torabi Moghadam, Chiara Genta, Patrizia Lombardi

Published in: *Sustainable Cities and Society*, *89*

Year: 2023

The platform developed for the city of Turin is an interactive Spatial Decision Support System (SDSS) dashboard, integrated into a web-based storytelling framework. This professional tool assists decision-makers in sustainable urban planning processes and seamlessly integrates with multi-criteria decision models at the city scale.

The platform serves several key objectives:

- To support decision-makers in sustainable urban planning for collaborative development of future transition strategies;
- To facilitate assessment of the city's sustainability performance through systematic evaluation of Key Performance Indicators (KPIs);
- To enhance scenario development by delivering targeted recommendations for local development planning;
- To identify municipal strengths and weaknesses through spatial distribution analysis, enabling efficient implementation of low-carbon action plans and optimizing investment decisions;
- To enhance stakeholder engagement and provide visualization capabilities for area-specific decision-making;
- To efficiently organize and maintain substantial georeferenced datasets and present results in diverse spatial formats;
- To provide decision-makers with a strategic framework for developing and evaluating future sustainable transformation scenarios;
- Ultimately, to equip urban stakeholders including researchers, planners, and public administrators with tools for developing, designing, managing, and monitoring low-carbon urban environments and selecting appropriate sustainability strategies.

The platform was primarily created by a research team from Politecnico di Torino. This initiative forms part of the MOLOC (Low Carbon Urban Morphologies) project, co-funded by the

Interreg Europe 2014-2020 Programme, with Turin serving as a principal participant alongside other European partners. Additional contributions and technical expertise were provided by Turin's municipal government, the DIST department, Energy Department (DENERG), and the Responsible Risk Resilience Centre (R3C).

The geographical application of the SDSS dashboard focuses on the city level, with Turin serving as the primary case study. While initially implemented in Turin, the methodological framework is engineered to be adaptable and applicable to comparable European urban environments. The underlying SNTool had previously been deployed at building and district scales, with this study aiming to extend its application to the broader urban context.

The underlying rationale for developing this platform stems from the recognition that urban systems significantly contribute to contemporary environmental challenges including Greenhouse Gas (GHG) emissions, energy consumption, and waste generation, despite occupying less than 10% of the Earth's surface. Cities are increasingly recognized as essential frameworks for addressing climate change and advancing sustainable development, as emphasized by Agenda 2030 and its Sustainable Development Goals (SDGs), particularly SDG 11. There exists an urgent imperative for cities to formulate carbon neutrality strategies, aligning with initiatives such as the European Green Deal. Conventional urban planning methodologies often prove inadequate for managing dynamic changes and environmental complexities, necessitating innovative and inclusive approaches.

Existing assessment tools frequently exhibit limitations including insufficient criteria, methodological shortcomings, and limited automation capabilities. Additionally, Turin is undergoing significant urban transformation following the decline of its industrial sector and is currently revising its General Masterplan to incorporate sustainable development principles, with aims to enhance cultural significance, foster innovation, and ensure social inclusion and equity. The dashboard addresses these challenges by providing a comprehensive, data-driven, and collaborative tool for urban sustainability assessment and planning.

The SDSS utilizes Esri ArcGIS Pro, ArcGIS Storymap, and ArcGIS Dashboard. It also incorporates the SNTool (Sustainable Neighborhood Tool), an Excel-based system for evaluating urban neighborhood sustainability performance. GIS technologies form the core of the system, enabling advanced data visualization, management, and spatial analysis.

It presents results in various spatial formats and illustrates the distribution patterns of Key Performance Indicators (KPIs). The system features dynamic mapping capabilities, allowing users to visualize changes and access detailed information layers. The integration of visual tools within the SDSS significantly enhances decision-making processes. A representative example of its interactive functionality is the intermodality urban facilities indicator dashboard, which presents comprehensive information layers and data.

Data Types and Georeferencing: The platform primarily utilizes empirical measured data at the urban scale. Data acquisition represents a critical yet challenging aspect due to data dispersion across various entities and interoperability limitations. The system incorporates diverse data types:

- Georeferenced data: Directly incorporates geometric information with alphanumeric values, including shapefiles for green spaces, transportation networks, and public services.

- Non-georeferenced data: Raw data, typically collected in Excel format, subsequently processed and linked to spatial datasets (e.g., census sections or coordinate points) using common identifier fields in the GIS environment.

- Raster data: Employed for indicators such as NDVI (Normalized Difference Vegetation Index) and Albedo, obtained from sources including ARPA Piemonte.

- Alphanumeric data: Connected to census sections for energy consumption and GHG emissions analysis, sourced from organizations including IREN Group, SIATEL, and Istat.

While certain datasets are classified as Open Data (e.g., specific transport information, Istat building heated areas), others are categorized as No-open Data (e.g., green spaces, IREN, SIATEL) or have Restricted access (e.g., ARPA Piemonte raster data). Data privacy considerations occasionally necessitate the utilization of aggregated information.

The platform monitors eight KPIs organized into five primary categories, providing a comprehensive integrated assessment of sustainability:

- Urban System: Land quality assessment (NDVI) and Intermodality of urban facilities.

- Energy: Total final thermal energy consumption and Total final electric energy consumption for residential buildings.

- Atmospheric Emission: GHG emissions from residential building energy use.

- Environment: Air quality (PM10 concentration) and Albedo of external surfaces.

- Social Aspects: Accessibility and proximity of essential public services to residential buildings.

The selection methodology for these KPIs involved a collaborative, multi-criteria approach implemented through a four-phase process: initial selection, hierarchical organization, final determination (utilizing the Simos-Roy-Figueira method in a workshop setting), and validation with stakeholders and public administration experts, ensuring the indicators are comprehensive and contextually appropriate.

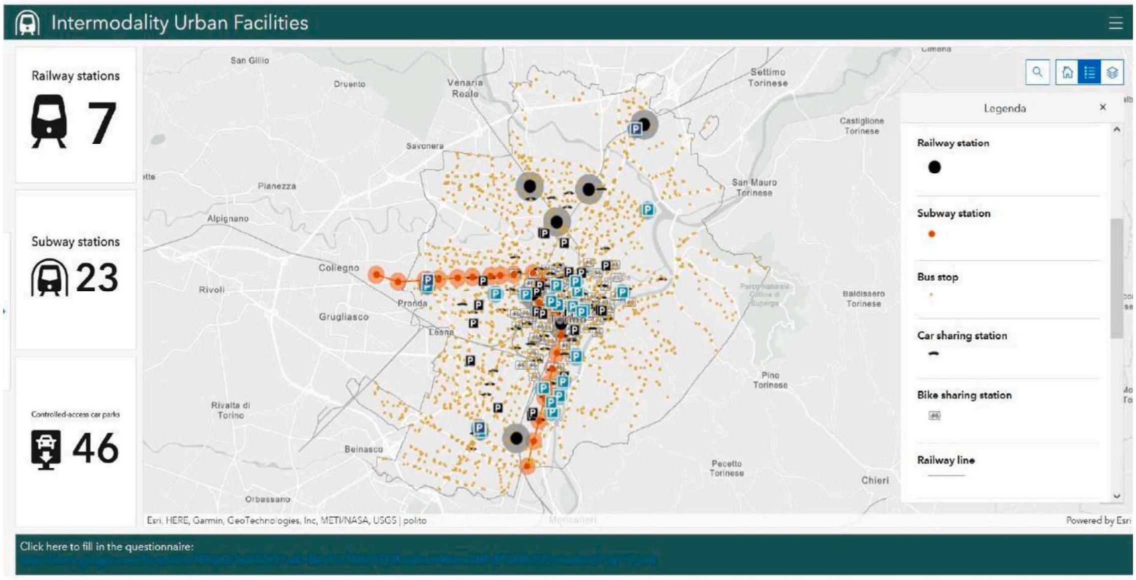
The platform provides essential capabilities for evaluating urban sustainability across economic, social, and environmental dimensions, positively influencing urban economies toward greater efficiency and innovation. It addresses critical contemporary challenges including Greenhouse Gas (GHG) emissions, energy consumption, and waste production in urban environments, aligning with the Agenda 2030 and its Sustainable Development Goals (SDGs), particularly SDG 11 on sustainable cities. By facilitating the assessment of urban sustainability performance through Key Performance Indicators (KPIs), the SDSS supports decision-makers in collaborative development of future transition strategies and scenario planning. It effectively identifies urban strengths and weaknesses, thereby facilitating implementation of low-carbon action plans and optimizing investment decisions. Ultimately, it equips various urban stakeholders—researchers, planners, decision-makers, and public administrators—with tools for developing, designing, managing, and monitoring low-carbon cities and selecting appropriate sustainability strategies.

The Turin SDSS exhibits numerous strengths. It functions as an interactive dashboard integrated into a web-based storytelling platform, providing intuitive functionality and supporting collaborative processes. A principal advantage is its capacity to efficiently manage and store substantial volumes of georeferenced data and present results in diverse spatial formats, offering clear visualization of KPI patterns. Notably, it employs empirical measured data at the urban scale, distinguishing it from studies that rely on estimated values. The collaborative, multi-criteria methodological approach for KPI selection, involving stakeholders and subject matter experts, ensures the selected eight indicators across urban systems, energy, atmospheric emissions, environment, and social dimensions are comprehensive and contextually appropriate. Its integration with the SNTool enables baseline scenario assessment and performance normalization, providing quantitative sustainability metrics. The framework additionally supports SWOT analysis to qualitatively interpret quantitative results, guiding the development of a strategic framework for future planning initiatives.

Despite its strengths, the implementation encountered significant challenges, primarily related to data acquisition. This process often proved resource-intensive and time-consuming due to data dispersion across various entities, interoperability limitations among data sources, and requirements for high-quality, quantitative information. Limited availability and reliability of comprehensive, standardized databases at the local level presented substantial obstacles. Additionally, data privacy considerations occasionally necessitated the use of aggregated data, though accuracy was maintained. The heterogeneity of data sources and the requirement for indicator-specific calculation methodologies introduced complexity and frequently required specialized expertise. The study also identifies a need to streamline the planning procedure for improved comprehensibility among all stakeholders, including non-specialists. The initial assessment of Turin's baseline scenario yielded a relatively low sustainability score (0.4 on a scale of -1 to 5), indicating significant areas requiring intervention.

The Turin case study directly influenced policy development and planning initiatives. It constituted an integral component of the MOLOC project and supported the comprehensive revision of Turin's General Masterplan. The study's outcomes have been incorporated into the revised city General Masterplan Technical Proposal. The strategic framework, informed by the SDSS and SWOT analysis, established sustainability guidelines for the new Masterplan, including objectives, strategies, and prioritized actions focused on energy efficiency and social dimensions to ensure sustainable and equitable urban development. Collaborative workshops involving public administration personnel and subject matter experts validated the strategic framework, ensuring alignment with urban planning objectives.

A significant advantage of the methodology is its transparency and adaptability. The methodological framework is designed to adapt to the specific territorial characteristics of different locations while addressing all sustainability dimensions, making it applicable to other comparable European urban environments. Urban stakeholders are encouraged to customize this assessment framework according to their project requirements and objectives, promoting broader implementation and facilitating comparative analysis of urban sustainability progress across different regions.



Click here to fill in the questionnaire:

Fig. 16: A visualization of the Spatial Decision Support System (SDSS) dashboard showcasing the Intermobility Key Performance Indicator.
source: Pignatelli et al., 2023

CHAPTER 3_METHODOLOGY AND INSTRUMENTS

3.1 Approach for SDG assessment in the case study

In the context of sustainable urban development, creating effective tools for measuring and monitoring progress toward Sustainable Development Goals (SDGs) has become increasingly important.

The ideal method for evaluating Sustainable Development Goals (SDGs) in a neighborhood georeferenced dashboard case study combines four key elements: strategic localization, robust data utilization, inclusive stakeholder engagement, and purposeful application of digital tools—all while addressing inherent limitations. This approach recognizes the pivotal role of cities and neighborhoods in achieving the 2030 Agenda due to their direct proximity to social, economic, and environmental challenges (Siragusa et al., 2021).

This methodological approach would be characterized by:

- **Localization and Granular Data:** Prioritizing the **localization of global SDG objectives** by utilizing **high-quality, timely, and disaggregated georeferenced data at the neighborhood or census tract level** to address specific local realities and disparities (United Nations Statistics Division, 2020);
- **Comprehensive Indicator Framework:** Developing an indicator framework that covers urban structure, environmental quality, socio-economic aspects, and governance, employing a **collaborative, multi-criteria approach** for selection to ensure contextual appropriateness (Pignatelli et al., 2023);
- **Integrated Geospatial Technologies:** Leveraging **Geographic Information Systems (GIS)** as the foundational technology for spatial analysis, visualization, and data integration from diverse sources like sensors and Points of Interest (Avtar et al., 2020);
- **User-Centered and Interactive Design:** Implementing a **user-centered design methodology** to create highly interactive dashboards that facilitate engagement for both specialists and general citizens, offering customizable visualizations and comparative analysis tools (Delfini et al., 2024);
- **Transparency and Participatory Governance:** Ensuring the platform promotes **transparency and accountability** by making public datasets readily available and fostering active citizen participation in urban planning and decision-making processes (Costa et al., 2024);
- **Adaptability and Replicability:** Designing the methodological framework to be **adaptable and transferable** to diverse urban contexts, allowing for customization to unique local conditions and facilitating comparative analysis across regions (Wang et al., 2024);

This technique is highly suitable for the city of Turin and, in specific, to evaluate its progress at neighborhood level due to several specific characteristics of the city and the tools already in use or developed for it:

- **Existing Framework for Granular Analysis:** While the interactive Spatial Decision Support System (SDSS) dashboard developed for Turin (Pignatelli et al.,2023) operates at the city scale, its underlying **SNTool (Sustainable Neighborhood Tool)** had been **previously deployed at building and district scales**. This demonstrates an established capacity and experience in applying sustainability assessments at a granular, sub-city level, directly relevant to neighborhoods;
- **Emphasis on Georeferenced Data and Spatial Analysis:** The Turin platform (Pignatelli et al.,2023) fundamentally relies on **georeferenced empirical measured data**, linking geometric information with alphanumeric values for elements like green spaces,

transportation networks, and public services to census sections or coordinate points. This theorically aligns perfectly with the need for precise, spatially disaggregated data crucial for neighborhood-level evaluation;

- **Comprehensive and Adaptable KPI Framework:** The selection of Key Performance Indicators (KPIs) for Turin (Pignatelli et al.,2023) involved a **collaborative, multi-criteria approach** encompassing urban system, energy, atmospheric emission, environment, and social aspects. This framework is designed to be **adaptable to specific territorial characteristics**, allowing customization to unique neighborhood priorities and conditions;
- **Policy Integration and Support for Urban Transformation:** Turin is actively revising its General Masterplan to incorporate sustainable development principles, and the SDSS outcomes have been **integrated into this revised plan** (Pignatelli et al.,2023), establishing sustainability guidelines. This indicates a municipal environment receptive to data-driven tools for urban planning and transformation, including at localized scales.

Despite the suitability of the methodological approach for Turin, it has to be noted that several critical limitations and issues can impede its effectiveness in a neighborhood georeferenced dashboard:

Firstly, **significant challenges exist regarding data availability, quality, and consistency at granular levels**. Substantial data gaps, methodological inconsistencies, and insufficient disaggregation, particularly at sub-national and neighborhood scales, compromise comprehensive reporting and accurate assessment. Acquiring reliable neighborhood-level data often requires substantial resources and faces challenges like privacy concerns and inconsistent local information systems.

Secondly, **existing SDG indicators and assessment methodologies are often not optimally designed for neighborhood application**, frequently lacking local relevance. Metrics primarily developed for national or city-wide monitoring may fail to capture context-specific nuances or adequately address the full spectrum of sustainability dimensions beyond just environmental factors.

Thirdly, **such platforms can demand high technical expertise and complexity to operate effectively**, potentially limiting their accessibility for general users. Despite efforts to maintain clear layouts, the abundance of tools may make them more suitable for IT or GIS specialists, hindering broader public engagement.

Fourthly, a fundamental conceptual challenge is the **lack of standardized “neighborhood” definitions, leading to measurement inconsistencies**. Administrative boundaries often do not align with actual social or functional neighborhood zones, creating “scale effects” and “zoning issues” that can distort assessments and obscure local disparities.

Finally, **insufficient local governance capacity and inadequate stakeholder engagement** present significant implementation barriers. Many local administrations lack the necessary human, technical, and financial resources to effectively implement global objectives at the neighborhood scale, and authentic community participation is frequently undervalued or ineffectively facilitated.

3.1.1 Case study: localized evaluation framework adopted

The evaluation framework adopted for the case study comes from the European Handbook for SDG Voluntary Local Reviews. It is a methodology designed to guide European local and regional governments in monitoring their progress towards the Sustainable Development Goals (SDGs). Its primary aim is to identify indicators that are both locally relevant and comparable across different cities and over time (Siragusa et al., 2022).

The methodology connects indicators to Sustainable Development Goals (SDGs) and their objectives through a **structured selection process driven by the relevance of each Goal at European and local levels**. Each SDG is analyzed for its overall importance, its relevance within the European context (considering EU policies), and its specific local dimension, including the capacity of cities to take action. This ensures that chosen indicators are pertinent to urban challenges and policies.

The framework prioritizes indicators in the following order:

- **Official and harmonized indicators** from European databases (e.g., Eurostat, European Environment Agency) or international organizations (e.g., OECD) receive top priority;
- **Official but not harmonized indicators** from local statistical offices or administrations are considered next, as they are generally expected to be available;
- **Experimental and harmonized indicators** from research centers, universities, or international institutions are used when official data is lacking;
- **Experimental and non-harmonized indicators** serve specific local contexts where other data types are unsuitable, requiring municipalities or third parties to collect information experimentally.

The selected indicators are explicitly linked to specific SDG targets, demonstrating how they measure progress towards those objectives. The 2022 edition of the Handbook features 72 example indicators that address 54 distinct SDG targets, ensuring that the chosen indicators are both locally relevant and allow for comparison across cities and over time, directly reflecting progress on SDG objectives.

The methodology of the Voluntary Local Review (VLR) can be adapted to the local specificities of Turin's georeferenced dashboard at the neighborhood level through several key theoretical refinements.

Firstly, an essential adaptation involves **enhanced data granularity and disaggregation**. The VLR framework's commitment to the "Leaving No One Behind" principle necessitates **disaggregated, high-quality data** to track progress and identify marginalized populations. For Turin's neighborhood-level dashboard, this means moving beyond city-wide aggregates to capture **intra-urban variations and specific spatial and social disparities** within its neighborhoods. This granular approach enables targeted interventions tailored to distinct local realities.

Secondly, the adaptation requires **customization of indicators**. Localizing the Sustainable Development Goals (SDGs) involves **adapting global objectives to specific local contexts** and developing relevant strategies. Turin's existing multi-criteria approach for Key Performance Indicator (KPI) selection, already validated with stakeholders and experts, provides a robust foundation for developing or refining indicators that genuinely reflect neighborhood-specific needs, such as access to local services or green spaces.

Thirdly, the methodology benefits from **leveraging advanced geospatial capabilities**. Turin's dashboard project is fundamentally **GIS-based**, enabling advanced data visualization, management, and spatial analysis. At the neighborhood scale, this capability is crucial for **detailed mapping of socio-environmental conditions** and dynamic visualization of accessibility patterns, ensuring that insights are spatially explicit and actionable for local planning.

Finally, the adaptation should focus on **deepening participatory governance**. The VLR itself is an **"interactive process"** designed to engage diverse stakeholders. Neighborhoods are uniquely recognized as **"hubs for participatory planning, cross-sector collaboration, and innovation"**. Turin can expand its current stakeholder engagement to involve local communities directly in defining priorities and co-creating strategies, thereby fostering local ownership and legitimacy of sustainability initiatives at the most relevant scale.

3.1.1.1 Selected indicators

The selection of indicators for Turin's georeferenced dashboard was guided by a **multi-step, participatory, and multi-criteria methodological framework**.

Initially, the process began with a **comprehensive baseline list of 178 indicators** from the CESBAMED Generic Framework, a system designed for assessing urban sustainability performance at neighborhood and building scales and 73 indicators from the European Handbook for Voluntary Local Review.

The pre-selection process resulted in 33 indicators for the PRIN TECH START project. Following another participatory phase, **9 indicators** were ultimately selected for implementation in the georeferenced dashboard at neighborhood scale.

The methodology needed **validation and adaptation to local specificities and data availability**. Selected KPIs were adjusted through data aggregation, name changes, unit adaptations, and modifications in calculation methods to try to captured dynamics at the neighborhood level. For spatial impact assessment, KPIs needed to be **homogeneously measurable, quantitative, and geo-referenced** across the analyzed area, and elaborable within a GIS environment. This meticulous process ensured the indicators accurately reflected Turin's sustainability patterns and criticalities in a specific area.

For Turin's georeferenced dashboard, **nine main indicators** were chosen to evaluate the city's sustainability performance.

These indicators are:

- **Accessibility to basic services**
- **Availability and accessibility of green areas**
- **Public transport accessibility**
- **Per capita electricity consumption**
- **Per capita thermal energy consumption**
- **Per capita municipal solid waste produced**

- **Population exposed to PM10/2.5**
- **Green quality**

Selected indicators and their methodologies at urban scale:

1. **“Accessibility to Basic Services”**
    - **Definition**: This indicator measures the **percentage of the population that can reach basic public services (divided by type) within a 10-minute walking distance**. It is also related to the “Availability and proximity of key public human services to residential buildings” indicator, which defines accessibility based on **pedestrian buffers of 800m, 500m, and 300m** from services like health and educational facilities, and public green spaces. These buffer distances correspond to estimated walking times (e.g., 500m to a 10-minute walk, 300m to a 5-minute walk, 800m to a 15-minute walk). The total amount and percentage of residential buildings within each buffer zone are calculated.
    - **Unit of Measurement**: %.
    - **Associated SDG Target**: Target 11.1: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums. It also links to SDG 1 (No Poverty).
    - **Methodology**:
        - **Data Collection**: Acquire georeferenced data for key public services (e.g., hospitals, local health agencies, pharmacies, educational facilities) and residential buildings. These are typically available as geometric (point) shapefiles, often as open data from city municipalities.
        - **Spatial Analysis (GIS)**: Utilize GIS tools to **define pedestrian buffer zones (e.g., 300m, 500m, or a distance corresponding to a 10-minute walk)** around each service point. Then, **calculate the total number or percentage of residential buildings falling within these buffer zones** relative to the total number of residential buildings in the area. GIS overlapping functionalities are crucial here.
    - The European Handbook also emphasizes the importance of mapping access to essential services. The specific walking distance (10 minutes) can be converted to a metric distance (e.g., 500m or 800ms) for consistent GIS application.
    - In the SNTool MED framework, this aligns with **G3.1 “Availability and Proximity of Key Services”**, which specifies measuring the percentage of inhabitants within an **800-meter walking distance** of at least three key services. This direct measurement of proximity allows for precise identification

of service gaps at the neighborhood level.

- This indicator is used to **define the pedestrian accessibility of residents** to key public human services such as health and educational facilities, and public green spaces. It helps to **identify the most critical areas excluded from planned accessibility zones**. Cartography, based on this indicator, is a useful tool for **highlighting urgent challenges and identifying critical areas** in urban planning. It contributes to **identifying social inequalities** and ensuring **equitable access to resources and opportunities**.

- **Limitations**: Fragmentation and scarcity of public services in densely populated peripheral areas can lead to decreased accessibility.

2. **“Availability and Accessibility Green Areas”**

   - **Definition**: This indicator describes the **availability of green areas per inhabitant** and the **percentage of the population that does not have access to green areas within a 10-minute walking distance**. More precisely, it measures the **share of the urban centre population without access to green urban areas within a 400-meter walk**. It is computed by analyzing the presence and area of green urban areas within walking distance from the served population. The methodology uses harmonized EU-wide data sources like Copernicus Urban Atlas 2018 land use/land cover data, JRC population figures at the highest spatial resolution, and TomTom street network 2018. It **does not include very small public green areas** not captured by Urban Atlas, nor does it provide information on the typology, effective access, or specific functions of these green urban areas.

   - **Unit of Measurement**: %.

   - **Associated SDG Target**: Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities. It also links to SDG 3 (Good Health and Well-being) and SDG 15 (Life on Land).

   - **Methodology**:

     - **Data Collection**: Obtain land use/land cover data (e.g., Copernicus Urban Atlas) and high-resolution population figures (e.g., JRC-GEOSTAT grid) for the urban area. Street network data is also required to calculate walkable distances.

     - **Spatial Analysis (GIS)**: Use GIS to identify green urban areas and then calculate the share of the urban center population with access to these areas within a specified walking distance (e.g., 400 meters).

     - **Output**: A share or percentage of the population with access to green areas.

- While the Turin case study uses “Quality of land” based on NDVI, this “Availability and Accessibility Green Areas” indicator focuses more on *access* than *quality*. The European Handbook’s “Population without green urban areas in their neighbourhood” is a direct conceptual match, emphasizing access.

- This directly corresponds to **A2.3 “Green Area Accessibility”** in SNTool MED, which calculates the “Percentage of inhabitants with accessibility to green areas” if they are within **300 meters of a publicly accessible green space of at least 0.5 hectares**. Additionally, **A2.1 “Availability of Green Urban Areas”** measures the “Proportion of all vegetated areas within the neighborhood boundaries in relation to the total area”. These metrics enable detailed spatial analysis of green space provision and access at the neighborhood scale.

- This indicator measures the **share of the urban center population without access to green urban areas** within a specific walking distance. It provides a **harmonized view** that enables **easy comparisons among cities**. High-resolution results can be used for analysis combined with **demographic, socio-economic, or environmental variables** to **address social inequalities** and to **prioritize intervention areas** (e.g., based on the availability of private gardens or building density). It is essential for **evaluating the environmental impact of urban development** and **guiding strategies for climate change adaptation and resource efficiency**. **Limitations**: This indicator may not capture very small public green areas or provide information on the typology, effective access, or functions of green spaces.

3. **“Public transport accessibility”**

- **Definition**: This indicator estimates the **percentage of the population living in a defined area that has access to a specific level of public transport service**. It is based on the **frequency of the service and the ease of reaching stops**. It specifically measures a city’s population’s access to services including **bus, tram, metro, and train**. The indicator categorizes the share of the population into **five different groups** based on the level of public transport services available within walking distance of their residences, ranging from no services to services with very high frequency. The calculation method is aligned with UN-Habitat metadata for indicator 11.2.1, considering **maximum walking distances of 500 meters for bus and tram stops and 1 kilometer for metro and train stops**, based on estimated willingness to walk. Residential population distribution is provided at the highest resolution available as input data. Data on public transport (stop locations and departure frequency) are sourced from open data initiatives, public transport operators, and regional/national organizations, while population data comes from the JRC-GEOSTAT 2018 grid and Urban Atlas, and street networks from TomTom. All these data are harmonized by the European Commission, DG REGIO, and provided at the level of urban centers (high-density clusters of 1 km² grid cells).

- **Unit of Measurement**: %.

- **Associated SDG Target**: Target 11.2: By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons. It is categorized as an **experimental** indicator. It also links to SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), and SDG 10 (Reduced Inequalities).

  - **Methodology:** The indicator is calculated using a method that aligns with **UN-Habitat metadata for indicator 11.2.1**, considering maximum walking distances to public transport stops (e.g., 500 meters for bus and tram stops, and 1 kilometer for metro and train stops) based on estimated willingness to walk. Data for public transport (including location of stops and frequency of departures) is sourced from **open data initiatives, public transport operators, and regional or national organizations**.

  - This matches **F1.1 "Performance of the Public Transport System"** in SNTool MED, which calculates the "Percentage of inhabitants that are within **400 meters walking distance** of at least one public transportation service stop" with a daily frequency of at least 20 trips. This allows for assessment of transport equity and connectivity within neighborhood boundaries.

  - This indicator helps to estimate the **percentage of the population having access to a specific level of public transport service**, based on service frequency and ease of reaching stops. Findings from its monitoring can be used to **benchmark cities** and to **simulate the effect of planned investments or network performance enhancements**. It should be used in conjunction with "Journeys to work by public transport" (an SDG9 indicator) to **properly assess the efficiency of the public transport system**. It is crucial for **improving urban liveability** and ensuring **equitable access to resources and opportunities**.

  - Challenges in calculating this indicator for new entries (urban centers not currently in the database) include the **availability of open data on public transport timetables** and the **spatial resolution of population data**. This indicator also includes elements related to **decarbonisation**. By encouraging a shift towards public transport, it supports efforts to reduce dependence on private vehicles, leading to **lower CO2 emissions** and contributing to climate action.

4. **"Per Capita Electricity Consumption" & "Per Capita Thermal Energy Consumption"**

  - **Definition**: This indicator provides information on **per capita domestic energy consumption, based on per capita gas expenditures**. This is also articulated as the "Total final thermal energy consumption for residential building operations" which measures the **average value of annual thermal energy consumption for residential buildings operations**. In the case of Turin, this was calculated using IREN and SIATEL energy consumption data, which was linked to specific buildings using ArcGIS.

  - **Unit of Measurement**: kWh/inhabitant or kWh/m²/year.

  - **Associated SDG Target**: Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix. It falls under the "Energy" category of KPIs.

- **Methodology**:
  - **Data Collection**: Obtain raw energy consumption data from utility providers (e.g., IREN, SIATEL). This data is often alphanumeric and may initially lack a territorial dimension.
  - **Data Spatialization**: Link non-georeferenced energy consumption data (e.g., from Excel) to spatial datasets like census sections or specific coordinate points using common identifier fields within a GIS environment. Disaggregate per sector of activity (e.g., residential, industrial) and per delivery point if possible.
  - **Calculation**: Compute the annual consumption per capita for both electricity and thermal energy.
  - **Output**: Annual consumption in kWh per inhabitant.
- In SNTool MED, **B2.4 "Total Final Electrical Energy Consumption for Building Operations"** measures "Aggregated annual total final electrical energy consumption per aggregated indoor useful floor area". While not strictly "per capita" by person, normalizing by floor area allows for a comparable metric of building energy performance at the neighborhood level. Data can be metered or estimated for specific buildings.
- The second indicator corresponds to **B2.1 "Total Final Thermal Energy Consumption for Building Operations"** in SNTool MED, which measures "Aggregated annual total final thermal energy consumption per aggregated indoor useful floor area". This directly assesses the energy performance of buildings, which are the primary units of a neighborhood.
- The first indicator provides information on **annual electricity consumption per municipality**. The data allows for **analysis of energy consumption** disaggregated by activity sector, which is useful for **designing specific local policies aimed at reducing consumption** or **redistributing the energy mix**. It is directly relevant to **decarbonization efforts**.
- The second indicator provides insights into **per capita domestic energy consumption based on gas expenditures**. In the case of Turin, it helped to identify that thermal energy consumption **exceeds benchmark thresholds**, likely due to an aging building stock and high retrofitting costs. It also tracks progress in **energy efficiency at the local level**, such as through the **expansion of district heating networks**. It serves as an indicator for **decarbonization elements**.
- A key adjustment involves overcoming the challenge of **spatializing non-georeferenced energy data**, often requiring linking it to census sections for urban-scale analysis.

5. **“Per Capita Municipal Solid Waste Produced”**

- **Definition**: This indicator describes the **waste collected per capita in a year, expressed in kilograms**. It is computed by dividing the **total amount of municipal waste (domestic and commercial) collected per capita in one year (in kg per capita)** by the total number of inhabitants. Municipal waste includes waste collected by or on behalf of municipal authorities and disposed of through waste management systems. It encompasses waste generated by commerce, trade, small businesses, office buildings, institutions (schools, hospitals, government buildings), and selected municipal services (e.g., park/garden maintenance, street cleaning, if managed as waste). It **does not include waste from municipal sewage networks or municipal construction and demolition waste**.

- **Unit of Measurement**: kg/inhabitant or kg per capita.

- **Associated SDG Target**: Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. It is categorized as an **official** indicator and is also linked to SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities).

- **Methodology**:

    - **Data Collection**: Obtain data on total municipal waste generated and population figures from official statistics (e.g., Eurostat City Statistics Database).

    - **Calculation**: Compute the ratio of total municipal waste generated in a year to the number of inhabitants in the city.

    - **Output**: Waste generated in kg per inhabitant.

- It is important to note a slight difference in emphasis compared to the SNTool MED. **D2.2 “Access to Solid Waste and Recycling Collection Points”** in SNTool MED focuses on the “Percentage of inhabitants with access to solid waste and recycling collection points within **400 meters walking distance**”. This still contributes to neighborhood assessment by evaluating the **availability and accessibility of waste infrastructure** at a local scale, though it does not directly measure the *volume* of waste produced.

- This indicator describes the **waste collected per capita in a year**. It can **inform municipal strategies** and be readily **presented and disseminated to the public**, as it is directly linked to individual consumption habits. It is an indicator that includes **decarbonization elements**.

6. **“Population Exposed to PM10/2.5”**

- **Definition**: This indicator measures the **number of people exposed to high**

concentrations of PM2.5/PM10.

  - For **PM2.5 Concentration**: It measures the **average concentration of PM2.5 in the past two years in European cities with over 25,000 inhabitants**, based on data from over 400 monitoring stations reported to the European Environment Agency (EEA).

  - For **Air quality - particulates <10mu concentration (PM10)**: It measures the **average value of the atmospheric PM10 concentration detected by control units**.

- **Unit of Measurement**: % for exposure; µg/m³ mean year for PM10 concentration.

- **Associated SDG Target**: Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. It also links to SDG 3 (Good Health and Well-being) and SDG 13 (Climate Action).

- **Methodology (based on European Handbook and Turin case study)**:

  - **Data Collection**: Obtain data on fine particulate matter (PM2.5) concentrations from ground monitoring stations, reported by environmental agencies (e.g., EEA, ARPA Piemonte).

  - **Spatial Assessment**: Utilize GIS to map the concentration levels. The EEA computes average concentrations for European cities over 25,000 inhabitants. For more granular analysis, research centers (e.g., JRC) use LUR models with higher resolution (100m) to produce detailed maps of concentrations, which can then be used to calculate exposed population.

  - **Output**: Percentage of population exposed or a direct measure of concentration.

- This aligns with **E1.2 "Particulate Matter (PM10) Concentration"** and **E1.1 "Fine Particulate Matter (PM2.5) Concentration"** in SNTool MED, which assess the "Number of days within a year that PM concentration exceeds the daily limit." These directly address local air quality issues within a neighborhood, allowing for targeted interventions.

- The concentration data provides essential information to **tackle air quality issues at the local level through specific policies**. It can be used to **rank European cities according to their average levels of fine particulate matter**. It is an indicator that directly contributes to **decarbonization efforts**.

- The primary consideration is the **spatial resolution of the data**; while city-level averages are available, more detailed municipal analysis benefits from higher-resolution mapping.

7. **“Green Quality”**

   - **Definition**: This indicator provides the **total quantity of green area in square meters through the NDVI (Normalized Difference Vegetation Index) based on satellite images**. Also referred to as “Quality of land,” it aims to verify the quality of the permeable areas of a city using the NDVI index, which describes the **vigor level of greenery**. NDVI is calculated as the ratio between the difference and the sum of the reflected near-infrared and red radiation. NDVI values are merged with shapefiles representing the geometries of green areas, and relevant values are statistically verified with established hotspot classification thresholds.

   - **Unit of Measurement**: mq (square meters) or nr (number, referring to the index value).

   - **Associated SDG Target**: Not explicitly listed with a specific SDG target in the provided table. However, “Quality of land” is categorized under “Built Urban System” KPIs. It implicitly supports overall urban sustainability and environmental health.

   - **Methodology**:

     - **Data Collection**: Obtain raster data (e.g., satellite imagery) to calculate NDVI values, and shapefiles representing urban green areas from environmental agencies or city authorities (e.g., ARPA Piemonte, City of Turin).

     - **Spatial Analysis (GIS)**: Merge NDVI values with the shapefiles of green areas. Use GIS tools to perform hotspot analysis (e.g., Optimized Hotspot classification) to identify areas with high or low quality greenery.

     - **Output**: The indicator value can represent the average NDVI for permeable areas or be visualized on a map showing general picture of green area quality.

   - SNTool MED includes **A2.5 “Green Zones and Ecosystem Services”** measuring the “Share of natural green areas on total green areas”, and **A2.4 “Green Zones Density”** assessing the “Density of green spaces within the neighborhood’s area”. While the SNTool MED documentation doesn’t explicitly state the use of NDVI for these, NDVI is a common method for calculating “vegetated areas” and “green areas” and can be applied as part of the assessment methodology to quantify these indicators at a fine-grained, neighborhood level.

   - This indicator, using the **NDVI (Normalized Difference Vegetation Index)**, is used to **verify the quality of the permeable areas of a city** and describe the **vigor level of its greenery**. It helps to **highlight areas where interventions are most necessary** to improve green quality. It supports the assessment of the **environmental health and ecological performance of urban**

environments.

- Challenges can arise in combining raster data with vector data. Green areas within urban fabric can be fragmented and of low quality.

8. **“Tree Cover for Local Microclimate Management”**

   - **Definition**: This indicator measures the **reduction of ambient temperature through evapotranspiration and shading**. This concept is directly addressed by indicators like “Albedo of external surfaces”, which measures the **ability of surfaces to reflect solar radiation** to reduce the heat island effect in urban areas. It implements a satellite measurement method from the ITACA Protocol, assigning a reflection coefficient to urban homogeneous surfaces based on their characteristics (e.g., asphalt = 0.1, lawn = 1). Another related indicator is “Newly planted trees”, which measures the **number of newly planted street trees and park trees** (trees, shrubs, bushes, hedges, and other woody vegetation on public land or areas with free public access). This indicator **does not include information on tree type and diversity**.

   - **Unit of Measurement**: Not explicitly stated for “riduzione della temperatura ambientale”; Albedo is measured in %; “Newly planted trees” is measured as a Number.

   - **Associated SDG Target**: Not explicitly linked to a target for “Copertura alberata per la gestione del microclima locale”. However, “Albedo” is under the “Environment” KPI category, and “Newly planted trees” is linked to SDG 15.1 (restoration of terrestrial and freshwater ecosystems). These efforts contribute to building urban resilience against climate threats and improving human health.

   - **Methodology**:

     - **Approach 1 (Albedo - from Turin KPI 7) (Pignatelli et al., 2023)** : This measures the ability of external surfaces (including vegetation) to reflect solar radiation. Identify homogeneous urban surfaces (e.g., asphalt, concrete, lawn) using satellite imagery (e.g., NDVI mosaic) and attribute a reflection coefficient to each. Calculate the overall Albedo value for the city area.

     - **Approach 2 (Tree Cover Density/Newly Planted Trees)**: While “Tree cover density” was found complex for harmonized data, the European Handbook introduced “Newly planted trees” as an official indicator for SDG 15.1. This measures the number of newly planted street and park trees. Own municipal records are recommended as data sources.

     - **Output**: Albedo value or number of newly planted trees.

   - This is covered by **I2.2 “Use of Vegetation to Provide Ambient Outdoor Cooling”** in SNTool MED, which uses “Leaf Area Index” (ratio of total vegetated surface area to total site area) as its indicator. Additionally, **I2.3 “Green Roofs”** (aggregate area of building roofs with vegetated material) also contributes. These indicators focus on localized strategies to mitigate heat island effects and improve microclimate directly within a neighborhood.

- This indicator measures the **reduction of ambient temperature through evapotranspiration and shading**. It is addressed by indicators like "Albedo of external surfaces," which measures the **ability of surfaces to reflect solar radiation** to **evaluate and identify new functional systems to reduce the urban heat island effect**. "Newly planted trees" also contributes by measuring the number of trees added, which supports the **restoration and preservation of terrestrial ecosystems** and implicitly **improves human health** and **urban resilience against climate threats**.

3.1.2 Review of existing tools' frameworks

The adaptation of the Voluntary Local Review (VLR) methodology to Turin's neighborhood georeferenced dashboard is discussed, providing a structured approach to sustainable urban development at the local scale. By integrating lessons from existing tools and addressing methodological challenges, this framework offers a pathway to more effective neighborhood-level sustainability assessment.

Learning from Existing Tools: Best Practices for Neighborhood Assessment

Several innovative approaches from international case studies can enhance Turin's neighborhood dashboard implementation. These methodologies can be categorized into data collection, spatial analysis, user engagement, and practical application domains.

1. Enhanced Data Collection and Dynamic Analysis: Eindhoven in Cijfers demonstrates the value of integrating **real-time data from meters and sensors** alongside traditional datasets, providing dynamic insights into urban performance. This approach enables up-to-the-minute monitoring of neighborhood conditions, capturing temporal variations that static data sources cannot reveal.

2. Multi-scale Spatial Analysis: To achieve finer spatial granularity, Turin's platform can implement DATA2GO.NYC's approach of presenting **highly localized data down to individual census tracts**. This enables nuanced understanding of intra-neighborhood variations. Complementing this, Eindhoven's feature allowing users to **define and group existing areas to create custom spatial units** provides analytical flexibility that transcends administrative boundaries, addressing the "scale effects" that often distort neighborhood assessments.

3. User Engagement Through Narrative Visualization: For enhanced accessibility and public engagement, Turin's dashboard can learn from Dublin Dashboard's innovative use of **"stories" to integrate text, interactive cartography, and multimedia**. This approach transforms complex data into engaging narratives, making technical information accessible to non-specialists and fostering broader stakeholder participation.

4. Practical Neighborhood Applications: To support practical planning decisions, the

platform could incorporate features inspired by Brampton's "My Brampton portal," which provides **precision-targeted local information by identifying nearby amenities and services with exact distance measurements** from user-specified locations. This directly addresses residents' daily needs and supports equitable service provision. Similarly, integrating analytical frameworks for **mobility and accessibility**, similar to the Hamilton study's method of mapping **accessible neighborhoods based on walking times to essential services**, would allow Turin's dashboard to visualize livability at a granular scale, optimizing urban interventions.

Comprehensive Methodology for Indicator Creation and Implementation

To address these challenges, a comprehensive methodology for creating and implementing neighborhood-level indicators has been conceptualized, rooted in a **multi-disciplinary GIS-based framework** and a **participatory planning process**.

This methodology follows four interconnected phases:

1. Selection of Indicators: The indicator selection process begins with a broad foundation of existing frameworks (e.g., CESBAMED) and proceeds through an iterative filtering process. This involves qualitative methods (expert interviews, focus groups with public administration) for preliminary selection, followed by quantitative ranking via online questionnaires to prioritize indicators based on local relevance. Multi-stakeholder workshops using Strategic Reference Framework (SRF) methods finalize the indicators set, integrating diverse perspectives. Critical validation ensures data availability and consistency across the study area, with necessary adjustments to calculation methods to ensure contextual appropriateness.

2. Data Collection and Spatial Assessment: This phase acknowledges the inherent heterogeneity of urban data (geo-referenced, non-geo-referenced, raster, alphanumeric) and its distribution across various entities. Geographic Information Systems (GIS) serve as the core tool for integrating, managing, analyzing, and visualizing these diverse datasets. The spatialization process links non-georeferenced data to spatial datasets using common identifiers, transforming raw information into mappable formats. This enables impact assessment to identify "hotspots" of strengths and weaknesses across neighborhoods, visualized through thematic maps that provide both quantitative and qualitative insights for decision-making.

3. Integration with Web-Based Platform: The evaluated KPIs and spatial data are integrated into an interactive web-based dashboard using platforms like Esri ArcGIS Pro, ArcGIS Storymap, and ArcGIS Dashboard. These tools enable visualization of dynamic maps, information layers, and KPI patterns. The Spatial Decision Support System (SDSS) incorporates Multi-Criteria Analysis (MCA) models (e.g., SNTool) to evaluate sustainability performance against benchmark values and assign weights to indicators. This provides quantitative scoring for baseline scenarios and supports the development of future transformation scenarios through data-driven "what-if" forecasts.

4. Strategic Framework and Policy Implementation: The final phase translates analytical insights into strategic planning through SWOT analysis, which qualitatively interprets quantitative results to identify specific strengths and weaknesses. This informs the definition of clear targets, strategies, and operational actions, with prioritization for critical issues such as energy efficiency or social equity. The framework supports decision-makers in formulating sustainable urban planning strategies and co-creating future transition pathways, as demonstrated in Turin where the process informed the structural revision of the city's General Masterplan.

This comprehensive methodology prioritizes stakeholder engagement, data-driven insights, and advanced geospatial technologies to facilitate informed and adaptable urban planning for sustainable development.

Neighborhood-Scale Implementation Using SNTool MED

Building on the methodological framework described above, the SNTool MED provides an integrated assessment approach specifically designed for sustainable neighborhoods and small urban areas in Mediterranean contexts. Based on the transnational Sustainable Built Environment (SBE) Method, it implements a "think globally, act locally" concept that addresses many of the challenges identified earlier.

1. **Hierarchical Assessment Structure:** The SNTool MED organizes its multi-criteria analysis into four hierarchical levels, providing a comprehensive framework that captures the complexity of neighborhood sustainability:
    - **Issues:** Broad themes relevant to neighborhood sustainability (e.g., Use of Land and Biodiversity, Energy, Water, Social Aspects, Climate Change).
    - **Categories:** More specific aspects within each issue (e.g., under "Use of Land and Biodiversity," categories include "Use of Land," "Green Urban Areas," and "Biodiversity and Ecosystems").
    - **Criteria:** Basic assessment entries used to evaluate neighborhood sustainability, each linked to an indicator.
    - **Indicators:** Physical quantities or qualitative scenarios that quantify the neighborhood's performance with respect to each criterion.
2. **Contextualization Process:** Addressing the challenge of local relevance, SNTool MED requires adaptation to local conditions, priorities, history, and socio-economic factors before assessment. This contextual adaptation occurs through three key steps:
    - **Selection of Active Criteria:** Users select criteria that will compose their local version of SNTool from a larger generic framework. A core set of Key Performance Indicators (KPIs) are mandatory and consistent across different cities, enabling comparability while still allowing for customization based on regional policies and territorial characteristics.
    - **Benchmarking:** This critical step defines the scoring scale for each selected criterion, establishing "minimum acceptable performance" (score 0) and "excellent performance" (score 5) benchmarks. These reference points are typically defined based on national/regional laws, technical standards, statistical data, scientific literature, or local reference values, ensuring that assessment is grounded in relevant standards.

  - **Weighting:** The relative importance of criteria, categories, and issues is established based on local sustainability priorities. Priority factors are assigned (from 1 for low priority to 5 for higher priority), and criteria are weighted based on "impact level" considerations (intensity, extent, and duration of potential effects). This ensures the final sustainability score reflects the unique priorities of the assessed neighborhood.

3. **Structured Assessment Process:** Once contextualized, the assessment proceeds through three systematic stages.

   - **Characterization:** In this initial stage, values for all quantitative indicators are calculated, and reference scenarios are selected for qualitative indicators. SNTool provides specific assessment methods for each criterion, ensuring methodological consistency.

   - **Normalization:** Each indicator's value is assigned a standardized performance score within an interval from -1 (negative performance) to +5 (excellent performance). This normalization uses linear functions for quantitative indicators and discrete values for qualitative indicators, enabling comparison across diverse metrics.

   - **Aggregation:** The normalized scores are aggregated through a weighted sum at multiple levels: first aggregating criteria within categories, then categories within issues, and finally producing an overall sustainability score for the neighborhood. This multi-level aggregation preserves information at different scales while providing an integrated assessment.

3.2 Web platform development workflow

3.2.1 Case study adaptation

The case study is located in the Regio Parco district of Turin, northeast of the city center. It is a heterogeneous area, undergoing significant transformation and with a continuously evolving identity.

Despite not being among the most central or well-known districts, Regio Parco offers several notable strengths that make it an area of interest:

- **Green spaces:** The district is characterized by its proximity to expansive green areas, particularly **Parco della Colletta**, a well-equipped space along the Po River, and **Parco Aurelio Peccei**, both enhancing residents' quality of life.
- **Urban regeneration:** Regio Parco has recently become the focus of significant redevelopment initiatives. The conversion of former industrial sites has enabled the development of new housing, public spaces, and services, transforming the social and urban landscape. This **building renewal** is attracting new residents, especially young couples and families.
- **Cultural and scientific hub:** The district is home to the prestigious **Campus Einaudi** of the University of Turin, a contemporary complex designed by Norman Foster. The presence of students and researchers creates a vibrant, dynamic environment with a rich cultural atmosphere.
- **Strategic location:** While not in the city center, Regio Parco maintains excellent connections to downtown Turin and other districts through a **comprehensive public transportation network** of buses and trams. Its location along the Po River also provides convenient pedestrian and cycling options.

The selected area of analysis is a small portion of the Regio Parco district, where the Research unit of Politecnico di Torino initiated research to monitor buildings' energy and environmental performance and their surroundings during renovation, maintenance, and management processes.

The case study's design is based on elements taken from the urban metabolism (UM) theory and related sustainability aspects at defined sub-city spatial scale (Geremicca & Bilec, 2024). Urban Metabolism (UM) conceptualizes cities as organisms with flows of resources and waste. UM relates to spatial units, which can be implemented at various scales to analyze urban systems and develop meaningful neighborhood-level indicators.

The "neighborhood scale" serves as a particularly valuable framework for urban sustainability assessments as it effectively captures social indicators and meaningful interactions (Pulgar et al., 2023).

Complementing this approach, "Local Resilience Units" function as "micro-territories" for planning purposes, connecting directly to emerging urban concepts like the "15 Minute City" (Brunetta et al., 2023). For energy balance planning at the neighborhood level, "energy zoning cells" provide useful analytical units, defined by solar potential and demand factors including construction timeline, population density, and land-use patterns (Amado et al., 2018).

At a more granular scale within neighborhoods, "individual dwellings" serve as fundamental units for measuring building energy consumption indicators (Torabi Moghadam et al., 2018).

Additional units such as "100 × 100 m cell-size output grids" can be considered for developing high-resolution spatial indicators within neighborhoods to measure SDG indicators at the intra-urban level (Aquilino et al., 2020).

"Census sections", indeed, offer individualized spatial units that enable detailed urban sustainability evaluations at the neighborhood scale (Lorenzo-Sáez et al., 2021).

Meanwhile, "functional urban agglomerations"—defined by clusters of developed land pixels and transport connectivity—help researchers assess urban change over time while maintaining neighborhood-level analytical integrity (Cardenas-Ritzert et al., 2024).

The case study's design primarily utilized census sections and their aggregation into the so called "Metabolic Units" as the main units of analysis. This aggregation was based on several unifying characteristics among the census sections, particularly their spatial proximity, and was considered suitable as base for the creation of the indicators at neighborhood scale.

3.2.2 Design process with GIS Software

Esri ArcGIS Pro was selected for creating the indicators at neighborhood scale. This prominent Geographic Information System (GIS) software, developed by Esri, is widely regarded as an industry standard for geospatial analyses and data management (Taylor et al., 2021).

Its suitability for neighborhood-scale analysis is attributed to several key capabilities:

- Firstly, ArcGIS Pro facilitates **detailed spatial data processing**. The software enables precise manipulation of data at fine-grained levels, such as parcels, through tools like "Append" and "Spatial Join," and supports conversions between raster and polygon formats, including the ability to erase incompatible land uses for suitability assessments in urban environments (Taylor et al., 2021).

- Secondly, it excels in the **integration of diverse data sources**. ArcGIS Pro allows for the overlay and analysis of various information layers, such as demographic, economic, and environmental data, which is crucial for achieving a comprehensive understanding of urban conditions, identifying trends, and pinpointing areas for specific interventions at a localized scale (Qwaider et al., 2023).

- For **advanced analytical applications**, the ArcGIS ecosystem provides tools like the Network Analyst extension. This is essential for calculating accessibility, defining influence buffers, and configuring street networks, all of which are vital for assessing local connectivity and mobility patterns within neighborhoods (Lorenzo-Sáez et al., 2021).

- Finally, its robust support for **automation and visualization** further enhances its utility. ArcGIS Pro can be integrated with programming languages like Python for automated geospatial workflows (Cardenas-Ritzert et al., 2024). It also supports the creation of interactive dashboards that visualize detailed, parcel-level data in both 2D and 3D, thereby offering clear insights for stakeholders and supporting data-driven decision-making in urban planning at the neighborhood level (Brunetta et al., 2023).

3.2.2.1 Data sources for SDG indicators for the case study

The research incorporated **spatial and temporal data** for developing the case study's indicators.

Spatial data served as the foundation, utilizing a Geographic Information System (GIS)-based framework with **georeferenced data**. This approach enabled comprehensive spatial evaluation and mapping of the indicators in the analyzed area, highlighting patterns and potential intervention areas. The data, available in raster and shapefile formats, was either directly collected as georeferenced information or systematically linked to spatial datasets through GIS capabilities.

Temporal data encompassed measurements obtained across defined timeframes, particularly annual thermal and electrical energy consumption figures. These time-specific metrics proved critical for evaluating current sustainability performance levels.

The study primarily utilized **open data** sources from municipal and regional portals. The **Geoportale Regione Piemonte - BDTRE** provided open geometric data for the street network, buildings, and their related information. The **Azzonamenti Statistici - Sezioni di censimento** dataset was essential as it contained polygons representing census sections—the infra-municipal territorial units that further subdivide statistical zones. Additional datasets were provided to the research team by the LARTU laboratory of Politecnico di Torino, while other temporal and building-scale data came from private sources.

It should be noted that most data needed for analysis at the neighborhood scale **was not available as open data**. The information required for this specific evaluation primarily relates to the **building scale**, making it a matter of **private data**.

Data currency presented another challenge. The case study relied heavily on shapefiles, which are valuable for spatial analysis but difficult to update. For example, the analysis used a census section database with geometries last updated on 01/01/2011, while the associated information was updated through 31/12/2023.

Recently, a new dataset containing the same census sections with updated geometries and information was uploaded to the open data portal. This development rendered the indicator's project prototype either obsolete or in need of revision—a process requiring a complete recalculation of all indicators.

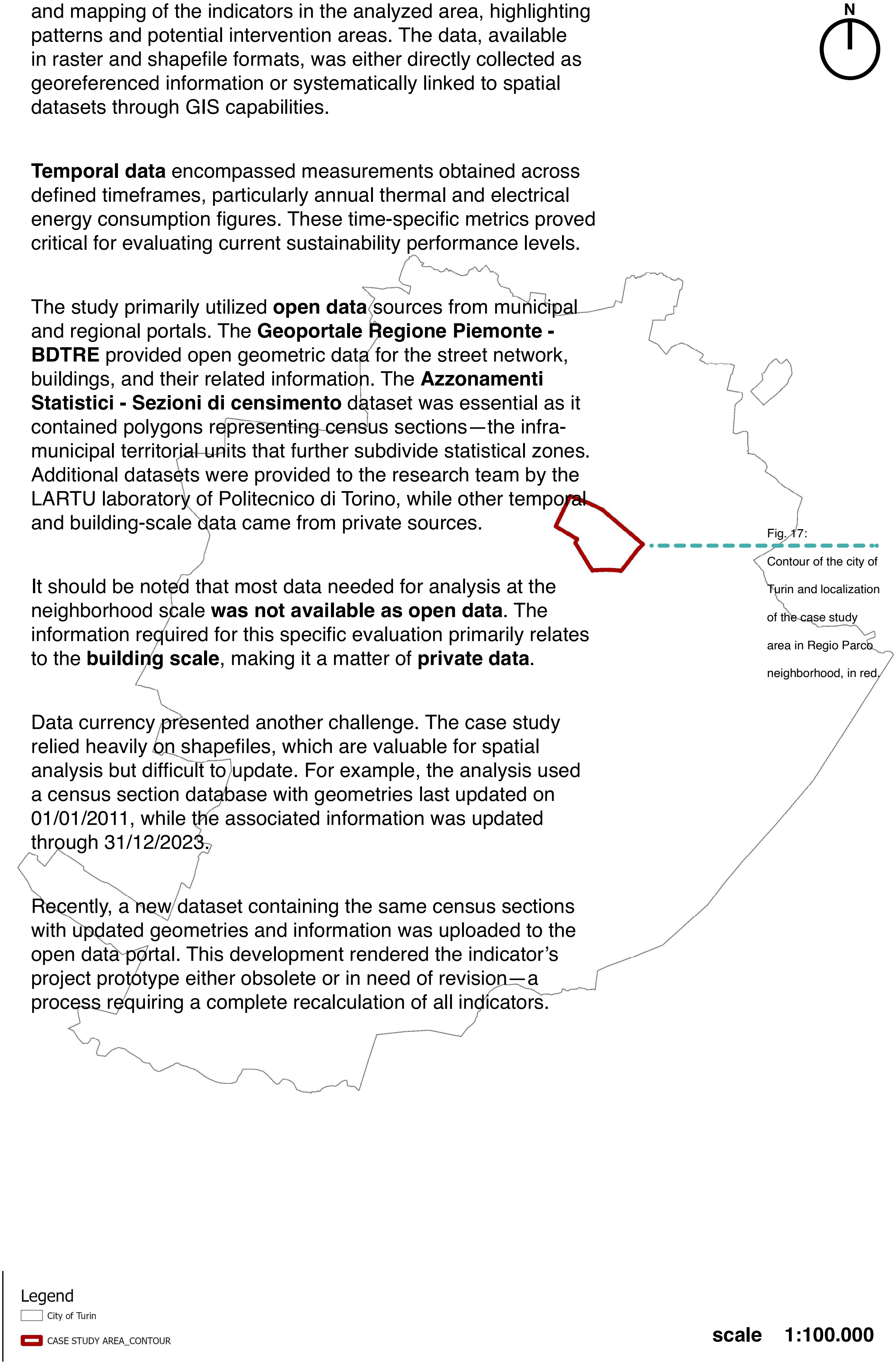


Fig. 17: Contour of the city of Turin and localization of the case study area in Regio Parco neighborhood, in red.

3.2.2.2 Creation of the base: “Metabolic Units”

The creation of basic spatial units of analysis, called “Metabolic Units”, followed a process that required the juxtaposition of different dataset and was mainly predetermined by the unit of research which started the work in the Regio Parco area.

Calculation methodology:

1. Projection of the shapefiles relative to buildings relative to BDTRE dataset on the Software ArcGis Pro.

2. Geoprocessing ‘Union’ of the two feature classes ‘main.un_vol’ and ‘main.cs_edi’ to create a basic layer for the buildings.

3. Projection of the shapefile of ‘sezioni_censimento_geo’ which contains the census units that will create the basis for the Metabolic Units.

4. Manual selection of relevant census units and creation of a unified layer from them.

5. Clip of the building’s shapefile with the union of the case study area to obtain a layer of buildings to use for the calculation of the indicators.

6. Manual selection of the polygons of interest to create the Metabolic Units, modifying the attributes table to group and name them according to a specific code predefined.

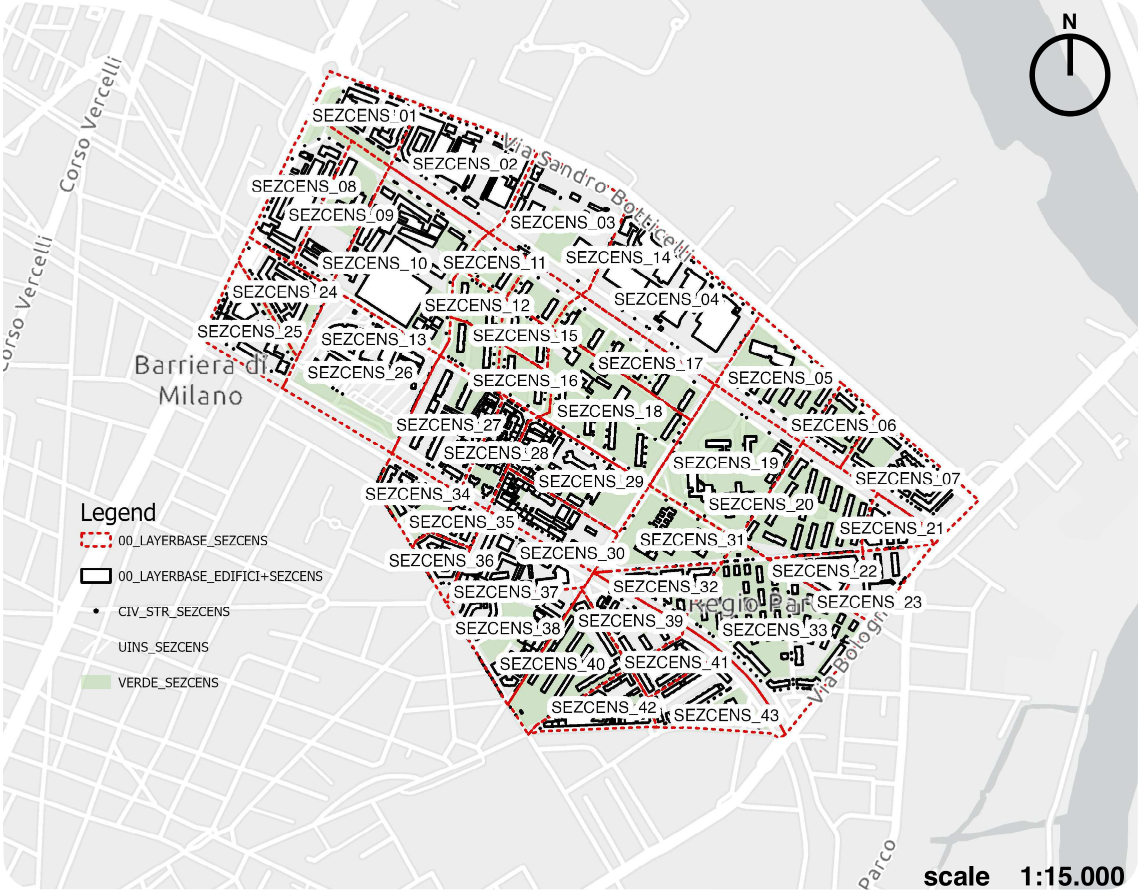
7. Geoprocessing ‘Pairwise dissolve’ to create the new Metabolic Units with the shapefile.

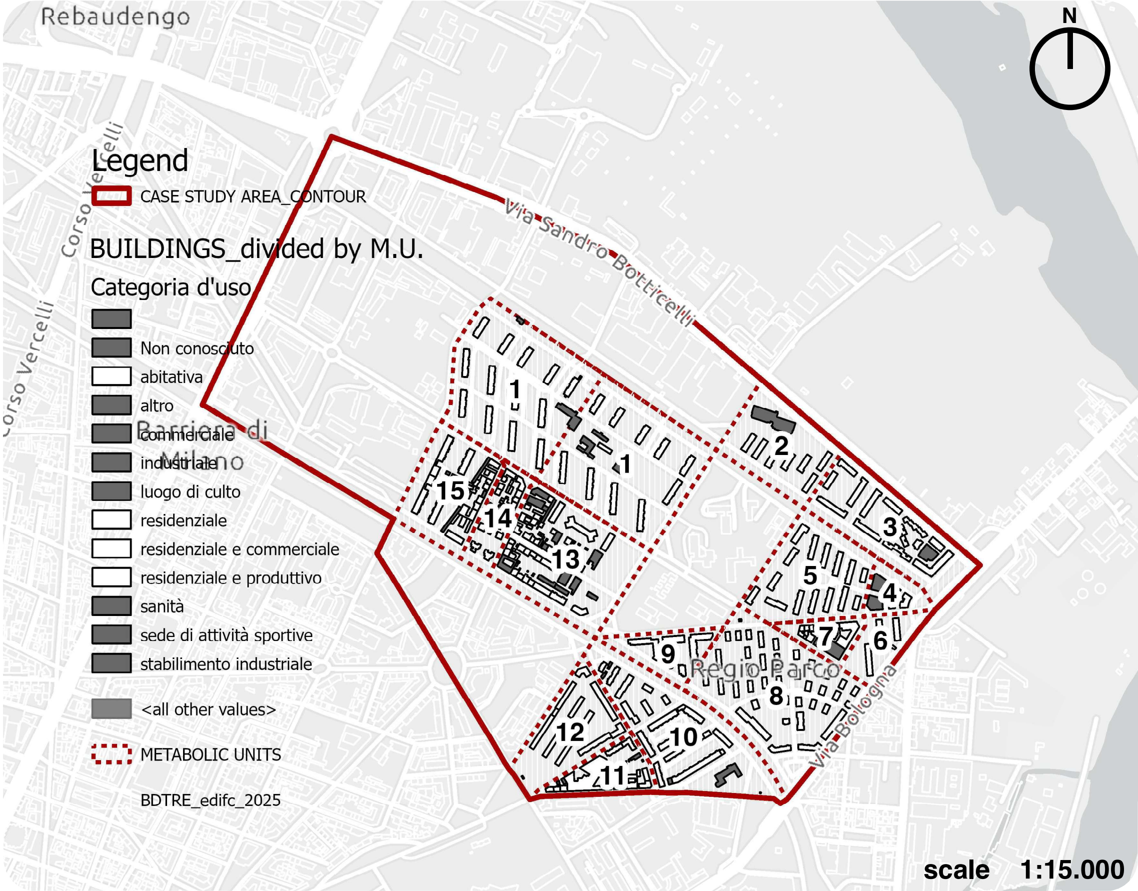
8. Creation of a layer that contains all Metabolic Units with related data: inhabitants, surface etc.

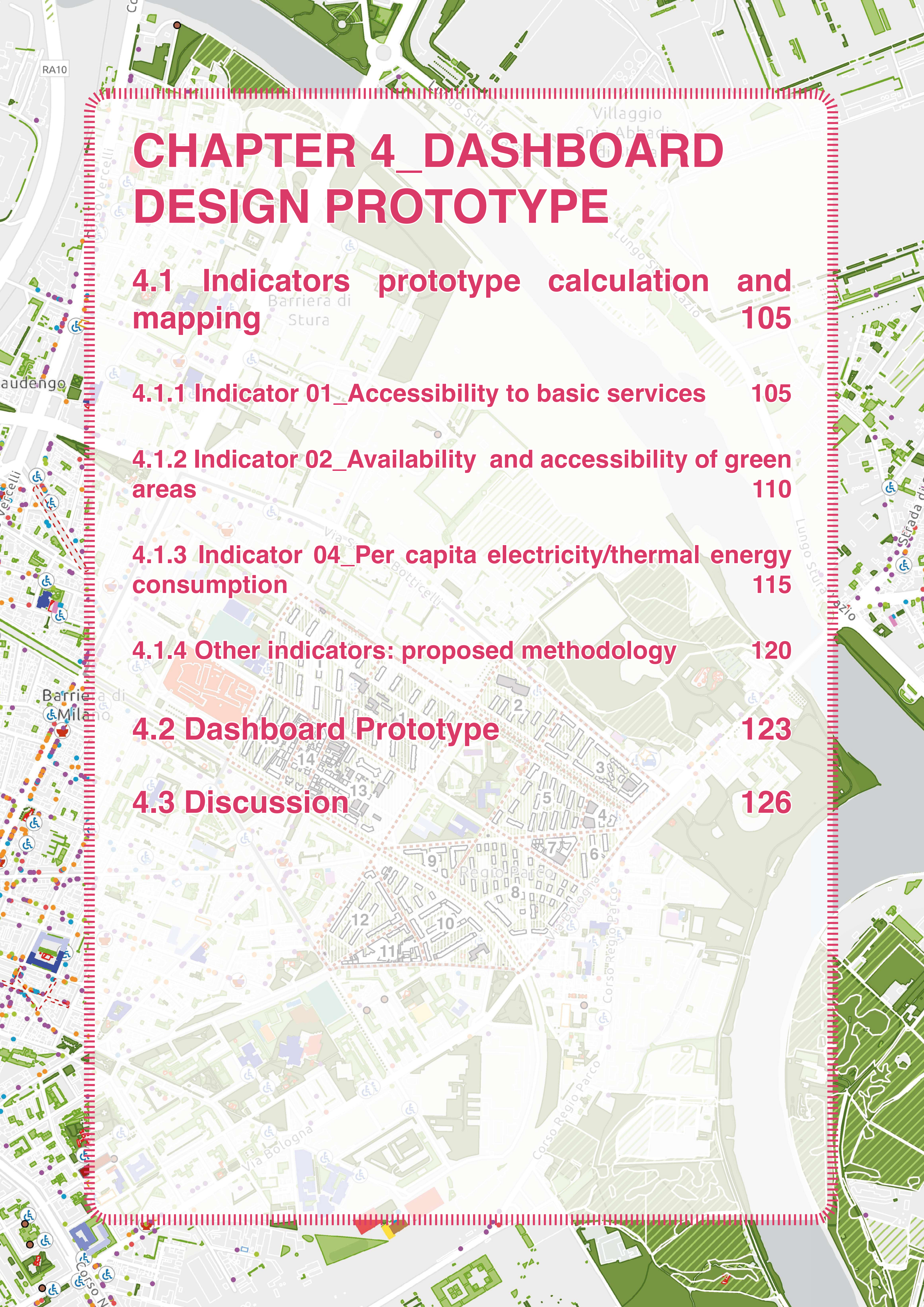
9. Modify data in the field view for each new Metabolic Unit and input data from ‘censimento 2023’.

Base of the calculation for the indicators: CENSUS SECTIONS and METABOLIC UNITS

CARTOGRAPHIC OUTPUT







CHAPTER 4_DASHBOARD DESIGN PROTOTYPE

4.1 Indicators prototype calculation and mapping

4.1.1 Indicator 01_Accessibility to basic services

Fig. 19:

Goal 11:
Sustainable cities and communities

source:
https://www.un.org/sustainabledevelopment/news/communications-material/

OBJECTIVE:

Calculating the level of accessibility to basic services **of each 'Metabolic Unit'** considering **the presence of minimum of 3 essential services within a 10-minute walk from the center of each M.U**.

These essential services are categorized according to the basic public services outlined in L.U.R. 56/1977 art. 21. This accessibility metric allows for detailed mapping of service deficiencies at the neighborhood scale.

EVALUATION METHODOLOGY:

Basic services must be strategically located to ensure optimal accessibility for residents, in fact, these services are essential for maintaining high quality of life in urban areas.

The methodology chosen shifts the calculation focus from the **service** to the **centroid of the metabolic unit**, making the indicator **demand-centric** (measuring how well each MU is served) rather than supply-centric (which merely counts residents within service buffers).

This analysis allows for evaluating whether service distribution meets required standards and identifies which basic service categories need improvement in the neighborhood to enhance quality of life.

DATA ACQUISITION:

FEATURE	U. of MEASUREMENT	FORMAT	SOURCE
education facilities			
school	/	.shp	Geoportale Comune di Torino (2025)
universities	/	.shp	Portale aperTO (2025)
other areas of common interest facilities			
churches	/	.shp	Portale aperTO (2025)
other religions	/	.shp	Portale aperTO (2025)
libraries	/	.shp	Geoportale Comune di Torino (2025)
ssa	/	.shp	Portale aperTO (2025)
markets	/	.shp	Portale aperTO (2025)
sport facilities	/	.shp	Portale aperTO (2025)
controlled access parking	/	.shp	Geoportale Comune di Torino (2025)
parking spaces for disabilities	/	.shp	Geoportale Comune di Torino (2025)
food markets	/	.shp	Geoportale Comune di Torino (2025)
other shops	/	.shp	Geoportale Comune di Torino (2025)
non-food shops	/	.shp	Geoportale Comune di Torino (2025)
mixed shops	/	.shp	Geoportale Comune di Torino (2025)
healthcare facilities			
hospital	/	.shp	Portale aperTO (2025)
pharmacy	/	.shp	Geoportale Comune di Torino (2025)
public green spaces			
green_other	/	.shp	LARTU Lab (2023)
green urban areas	/	.shp	LARTU Lab (2023)

Fig. 20:
Example of the projection of the layers in a M.U.

(source: own elaboration)

CALCULATION METHODOLOGY:

INDICATOR 01: Score of M.U. accessibility to basic services (access to at least 3 key services within a 10-minute walk from the center of the M.U.).

1. **Define accessibility zones based on walking distance for each M.U. centroid:**

    - For each Metabolic Unit: calculate from the **centroid** the area reachable on foot in 10 minutes using a tool for the creation of the isochrones.

    - The selected tool is **ORS Tools Plugin for QGIS**. This tool connects to the OpenRouteService through an API (Application Programming Interface). The service processes requests using **OpenStreetMap** (OSM) data and returns isochrone polygons. Most OSM data, especially in urban areas, is highly detailed and accurate, ensuring high-quality results.

2. **Calculate the typologies of services present for each M.U.:**

- Project and count the **types** of services present in each Metabolic Unit isochrone (**educational facilities, other areas of common interest facilities, healthcare facilities, public green spaces**).

- If **types ≥ 3** = M.U. is “served” (=1), otherwise 0.

Prerequisites:

- Layer **M.U.** (polygons) with field Total number of residents for M.U. (or associated population).

- Layer **Services** (points) with field type (school, hospital, green areas, etc.).

CALCULATION STEPS (based on ArcGIS Pro / QGIS):

1. **M.U. Centroid:**

- *Geoprocessing Tool*: **Feature To Point** of each Metabolic Unit → creates UM_centroids.

2. **Pedestrian Isochrones:**

- Use ORS Tools Plugin in QGIS to create **isochrones** based on walking distance starting from the centroids of the Metabolic Units.

    1. In the **Processing Toolbox**, search for:

        ☐ ORS Tools → Isochrones → Isochrones from Point-Layer.

    2. Set the parameters:

        ☐ **Centroid layer.**

        ☐ **Travel mode**: *foot-walking*.

        ☐ **Range type**: time (minutes).

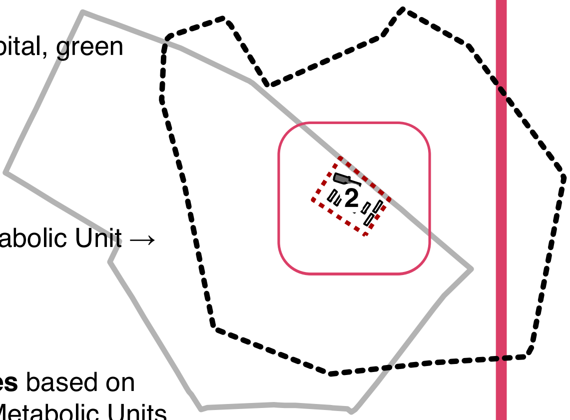


Fig. 22:
Example of a **ISOCHRONE (10 min footwalking) from CENTROID of M.U. 2**

(source: own elaboration)

Fig. 21:
Example of the service type count in in a M.U. isochrone

(source: own elaboration)

- ☐ **Range**: 10

3. Click *Run* → QGIS generates polygons of areas reachable within 10 minutes on foot.

1. **Service Type Count:**

- **Project** on ArcGis Pro the layers related to the basic services of the city area.
- Create a new layer of BASIC SERVICES to use just for calculation of the indicators.
    - Add the **field** type to each layer related to BASIC SERVICES specifying which kind of service represents that layer.
    - Geoprocessing **“Merge”** to create different layers, according to their feature type (polygon or point) containing all the features of the basic services.
    - Geoprocessing **“Feature to Point”** to transform the polygons layers associated to the services into point layers.
    - Geoprocessing **“Merge”** to create an aggregated layer containing all the services points: BS_points_merge
- **Calculate** the number of service types per ISOCHRONE:
    - Geoprocessing **Intersect** each U.M. ISOCHRONE layer with the layer of the points containing the basic services. This will associate each accessible basic service with the M.U. isochrone in which it falls.
    - Geoprocessing **Summary Statistics** for the layers of the intersection: Statistics = COUNT by type.

Result: for each **M.U.**, number of service **types** within 10 minutes by walking on foot.
To enhance the robustness of the evaluation, the following complementary calculations could be considered:

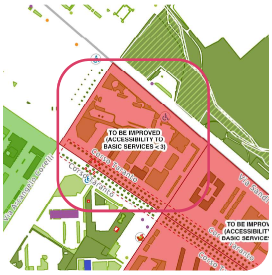


Fig. 23:
Example of the calculation of the accessibility level on the M.U. 2

(source: own elaboration)

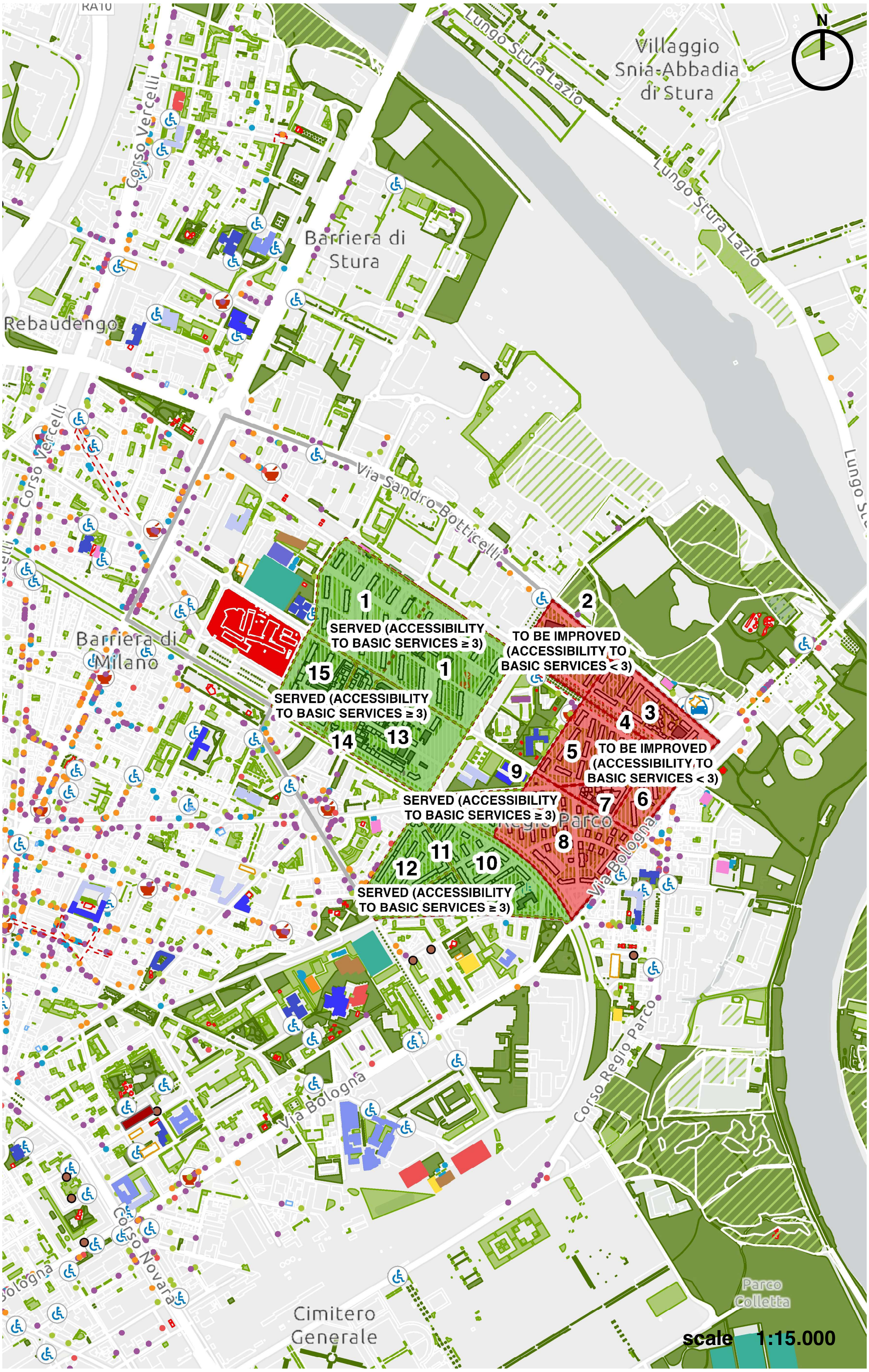
- **Calculate the Accessibility Level:**
    - Export the data and use an Excel table to calculate if each main typology of basic service (**educational facilities, other areas of common interest facilities, healthcare facilities, public green spaces**) is ≥ 3 for each M.U.; if not, the M.U. is considered ‘To be improved’.
    - Assign an “Accessibility Level” to each M.U. based on the count of distinct service types:
        - ☐ **Level 1 (High):** All 4 types of basic services are accessible.
        - ☐ **Level 0 (Low):** No type of basic services are accessible according to the defined criteria.

Cartographic Outputs

- **Choropleth map by M.U.**: **Served** (if types ≥ 3)**/To be improved** (if types < 3).

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES

CARTOGRAPHIC OUTPUT



Legend

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES BY M.U.

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES BY M.U.

- ■ SERVED (ACCESSIBILITY TO BASIC SERVICES ≥ 3)
- ■ TO BE IMPROVED (ACCESSIBILITY TO BASIC SERVICES < 3)

BUILDINGS_divided by M.U.

Categoria d'uso

- ■
- ■ Non conosciuto
- □ abitativa
- ■ altro
- ■ commerciale
- ■ industriale
- ■ luogo di culto
- □ residenziale
- □ residenziale e commerciale
- □ residenziale e produttivo
- ■ sanità
- ■ sede di attività sportive
- ■ stabilimento industriale

- ■ <all other values>

- ⬚ METABOLIC UNITS

scuole_aree_geo

ORDINE

- ■ SCUOLA D'INFANZIA
- ■ SCUOLA PRIMARIA
- ■ SCUOLA SEC. I GRADO
- ■ SCUOLA SEC. II GRADO

- ■ <all other values>

universita_aree_geo

DENOMINAZI

- ■ Istituto di studi superiori
- ■ Politecnico di Torino
- ■ Scuola Universitaria
- ■ Universita' di Torino

- ■ <all other values>

- □ chiese_aree_geo

- □ altri_culti_aree_geo

- ■ biblioteche_aree_geo

- ● strutture_socio_assistenziali_geo

- ⬚ mercati_geo

impianti_sportivi_aree_geo

DISCIPLINA

- ■ ARRAMPICATA
- ■ ATLETICA
- ■ ATTIVITA' AL CHIUSO
- ■ BASEBALL
- ■ BASKET
- ■ BOCCIODROMO
- ■ BOCCIOFILA
- ■ CALCETTO
- ■ CALCIO
- ■ CANOA
- ■ CICLISMO
- ■ EDIFICI DI PERTINENZA
- ■ GHIACCIO
- ■ GOLF
- ■ HOCKEY SU PRATO
- ■ PALAZZETTO
- ■ PALESTRA
- ■ PALLAMANO
- ■ PALLAVOLO
- ■ PIASTRA POLIVALENTE
- ■ PISCINA COPERTA
- ■ PISCINA SCOPERTA
- ■ ROLLER
- ■ SCHERMA
- ■ SOFTBALL
- ■ STADIO CAMPO CALCIO
- ■ STADIO GRADINATA
- ■ STADIO STRUTTURA
- ■ TAMBURELLO
- ■ TENNIS
- ■ TIRO CON ARCO

- ■ <all other values>

- 🚗 parcheggi_accesso_controllato_geo

- ♿ parcheggi_disabili_geo

attivita_commerciali_geo

TIPO_MER

- ● .
- ● ALIMENTARI
- ● ALTRO
- ● EXTRALIMENTARI
- ● MISTA

- ● <all other values>

- ■ ospedali_aree_geo

- ⚕ farmacie_geo

- ▨ VERDE_altro

VERDE

TIPO

- ■
- ■ area cani
- ■ giardino
- ■ giardino alberato
- ■ giardino sottocostruito
- ▨ giochi bimbi

- ■ <all other values>

- □ CASE STUDY AREA_CONTOUR

BDTRE_edifc_2025

Fig. 25:

Goal 11:
Sustainable cities
and communities

source:
https://www.un.org/sustainabledevelopment/news/communications-material/

4.1.2 Indicator 02_Availability and accessibility of green areas

OBJECTIVE:

To calculate the level of **accessibility to public green spaces** for each 'Metabolic Unit' (M.U.).

This involves determining the presence of public green spaces within **300 meters of a publicly accessible green space of at least 0.5 hectares,** corresponding approximately to a **6 minutes walk** from the center of each M.U.

Additionally it is calculated the **"Availability of Green Urban Areas"** indicator that measures the "Proportion of all vegetated areas within the neighborhood boundaries in relation to the total area".

This allows for detailed mapping of green space deficiencies at the neighborhood scale, contributing to the quality of life in urban areas.

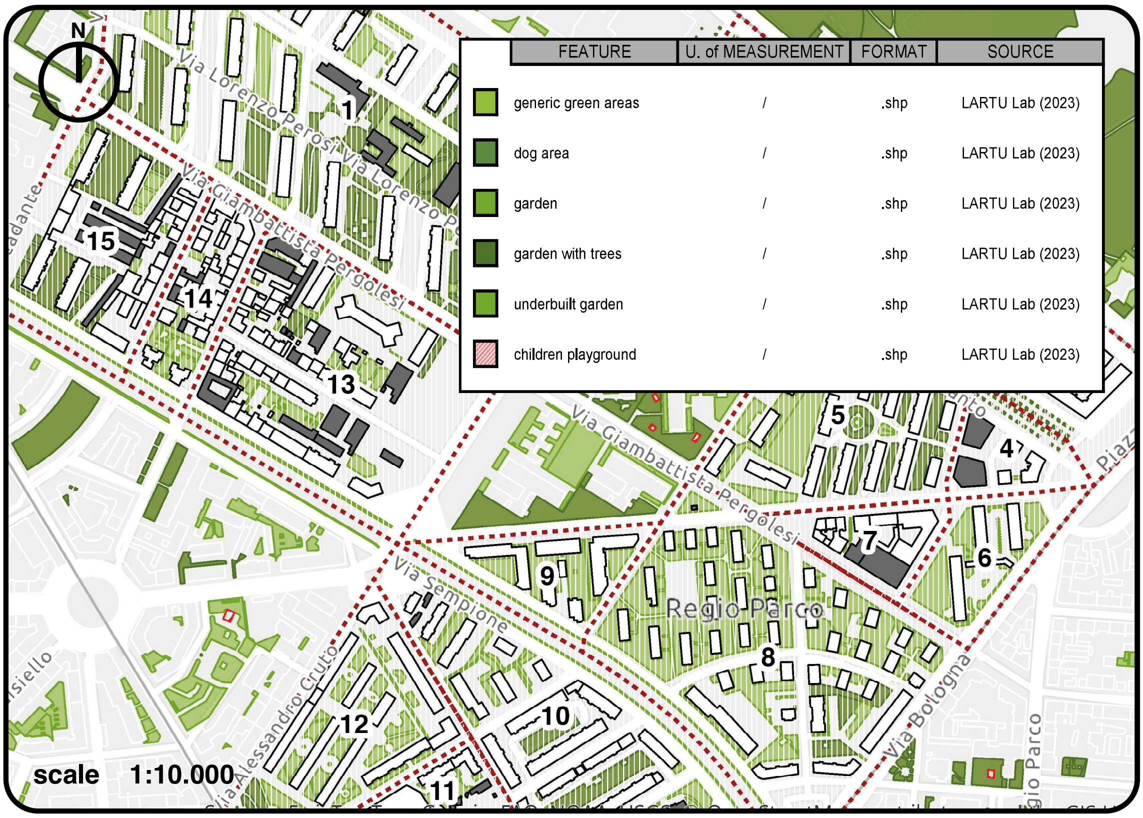
EVALUATION METHODOLOGY:

The chosen methodology is **demand-centric**, shifting the calculation focus from the green space itself to the centroid of the Metabolic Unit.

This measures how well each M.U. is served by green areas, rather than just counting residents within green space buffers.

This analysis helps evaluate whether green space distribution meets required standards and identifies areas needing improvement.

DATA ACQUISITION:



	FEATURE	U. of MEASUREMENT	FORMAT	SOURCE
🟩	generic green areas	/	.shp	LARTU Lab (2023)
🟩	dog area	/	.shp	LARTU Lab (2023)
🟩	garden	/	.shp	LARTU Lab (2023)
🟩	garden with trees	/	.shp	LARTU Lab (2023)
🟩	underbuilt garden	/	.shp	LARTU Lab (2023)
▨	children playground	/	.shp	LARTU Lab (2023)

Fig. 26:

Extract of the projection of the base for INDICATOR 02: the green areas and the Metabolic Units.

(own elaboration, made with ArcGis Pro software)

CALCULATION METHODOLOGY:

INDICATOR 02: Score of M.U. accessibility to public green spaces (access to green spaces of at least 0.5 hectares within 300 meters from the center of the M.U.) + availability of Green Urban Areas.

Fig. 27:
Example of the projection of the layers in a M.U.

(source: own elaboration)

1. **Define accessibility zones based on walking distance for each M.U. centroid:**

- For each Metabolic Unit: calculate from the **centroid** the area reachable on foot in 6 minutes using a tool for the creation of the isochrones.
- The selected tool is the **ORS Tools Plugin for QGIS**, which connects to OpenRouteService via an API (Application Programming Interface).

1. **Calculate the typologies of services present for each Metabolic Unit:**

- Project and count the ***number* of public green spaces (of at least 0.5 hectares) within 300 meters from the center of each M.U..**
- If ***number* of public green spaces (of at least 0.5 hectares) ≥ 1** ⇒ M.U. is “served” (=1), otherwise 0.
- Project the total surface of green areas and count the proportion of all vegetated areas within the M.U. boundaries in relation to the total area of the M.U.

Prerequisites:

- Layer **M.U.** (polygons) with field Total number of residents for M.U. (or associated population).
- Layer **Green Areas** containing all the categories of green areas, in particular “public green spaces”.

CALCULATION STEPS (based on ArcGIS Pro / QGIS):

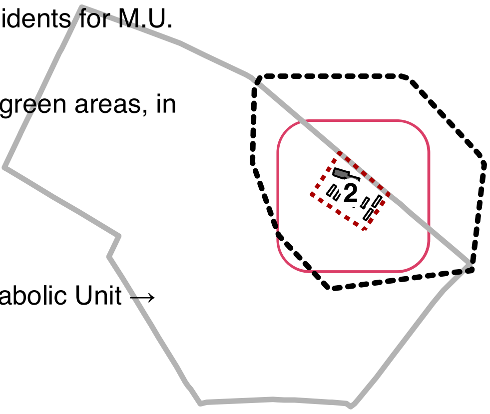


Fig. 28:
Example of a **ISOCHRONE (6 min footwalking) from CENTROID of M.U. 2**

(source: own elaboration)

1. **M.U. Centroid:**

- *Geoprocessing Tool*: **Feature To Point** of each Metabolic Unit → creates UM_centroids.

1. **Pedestrian Isochrones:**

- Use ORS Tools Plugin in QGIS to create **isochrones** based on walking distance starting from the centroids of the Metabolic Units.
    1. In the **Processing Toolbox**, search for:
        - ☐ ORS Tools → Isochrones → Isochrones from Point-Layer.
    2. Set the parameters:
        - ☐ **Centroid layer.**
        - ☐ **Travel mode**: *foot-walking*.

Fig. 29:
Example of the service type count in in a M.U. isochrone

(source: own elaboration)

    - **Range type**: time (minutes).
    - **Range**: 6

  1. Click Run = QGIS generates polygons of areas reachable within 6 minutes on foot.

2. **Green areas Count:**

- **Project** on ArcGis Pro the layers related to the green areas of the city area.
- Geoprocessing **"Feature to Point"** to transform the polygons layers associated to the green areas into point layers.
- Geoprocessing "**Intersect"** each U.M. ISOCHRONE layer with the layer of the points containing the green areas. This will associate each accessible green area with the M.U. isochrone in which it falls.
- Geoprocessing "**Summary Statistics**" for the layers of the intersection: Statistics = COUNT by type.
- Count number of public green spaces ≥0.5 ha within each isochrone.

→ for the indicator of Avaiability of green areas:

- **Calculate M.U. total area** (field Area_MU).
- **Calculate vegetated area** per M.U. (field Area_Veg).
- **Compute proportion on Excel**: Availability (%) = (Area_Veg / Area_MU) × 100 & Availability for each M.U. (%) = (Area_Veg / Area_s_U.M.) × 100

To enhance the robustness of the evaluation, the following complementary calculations could be considered:

- **Calculate the Accessibility Level:**
    - Export the data and use an Excel table to calculate if the green public areas ≥ 0.5 ha are ≥ 1 for each M.U.; if not, the M.U. is considered 'To be improved'.
    - **Assign score**: If count ≥1 ⇒ Accessibility = 1 (served), else 0 (to be improved).

Fig. 30:
Example of the calculation of the accessibility level on the M.U. 2

(source: own elaboration)

Cartographic Outputs

- **Choropleth map by M.U.**:
    - **Served** (if green public area 0.5 hectares ≥ 1)**/To be improved** (if types < 0).

INDICATOR 02_AVAIABIILITY AND ACCESSIBILITY OF GREEN AREAS

CARTOGRAPHIC OUTPUT

Legend

⬚ METABOLIC UNITS

URBAN GREEN AREAS_ACCESSIBILITY CALCULATION

TIPO

🟩
🟩 area cani
🟩 giardino
🟩 giardino alberato
🟩 giardino sottocostruito
▨ giochi bimbi

IND 02_ACCESSIBILITY TO PUBLIC GREEN SPACES

ISOCHRONES 6min INTERSECTION WITH GREEN AREAS ≥ 0.5 hectars - M.U. TO BE IMPROVED

☐ 0

AV. GREEN AREAS_M.U.

TIPO

🟩
🟩 area cani
🟩 giardino
🟩 giardino alberato
🟩 giardino sottocostruito
▨ giochi bimbi

🟩 <all other values>

METABOLIC UNITS

Avaiability of urban green areas (on M.U. total area) (%)

🟩 0.000000 %
🟩 0.000001 % - 1.000000 %
🟩 1.000001 % - 2.000000 %
🟩 2.000001 % - 4.000000 %
🟩 4.000001 % - 6.000000 %

☐ CASE STUDY AREA_CONTOUR

BUILDINGS

Fig. 32:

Goal 7:
Affordable and clean energy

source:
https://www.un.org/sustainabledevelopment/news/communications-material/

4.1.3 Indicator 04_Per capita thermal/electric energy consumption

This indicator, in its first part, was initially calculated using a dataset containing estimation of thermal energy consumption per building.

However, this dataset lacked the necessary information for proper neighborhood-level evaluation. It was incomplete for the lack of a great part of the buildings estimations and, as a consequence, the calculations showed that the indicator required a different methodology.

The **M.U. centric** methodology, developed later, can be effectively adapted for this case study, making the estimation of the indicator much more straightforward.

The indicator is presented here to show the results without the M.U. methodology, demonstrating the need for a new calculation method.

DATA ACQUISITION:

Domestic thermal energy consumption per capita based on expenses per capita for electricity.

Source: ATC Torino. These data were given as a database to geolocalize, associated to the street addresses of the buildings.

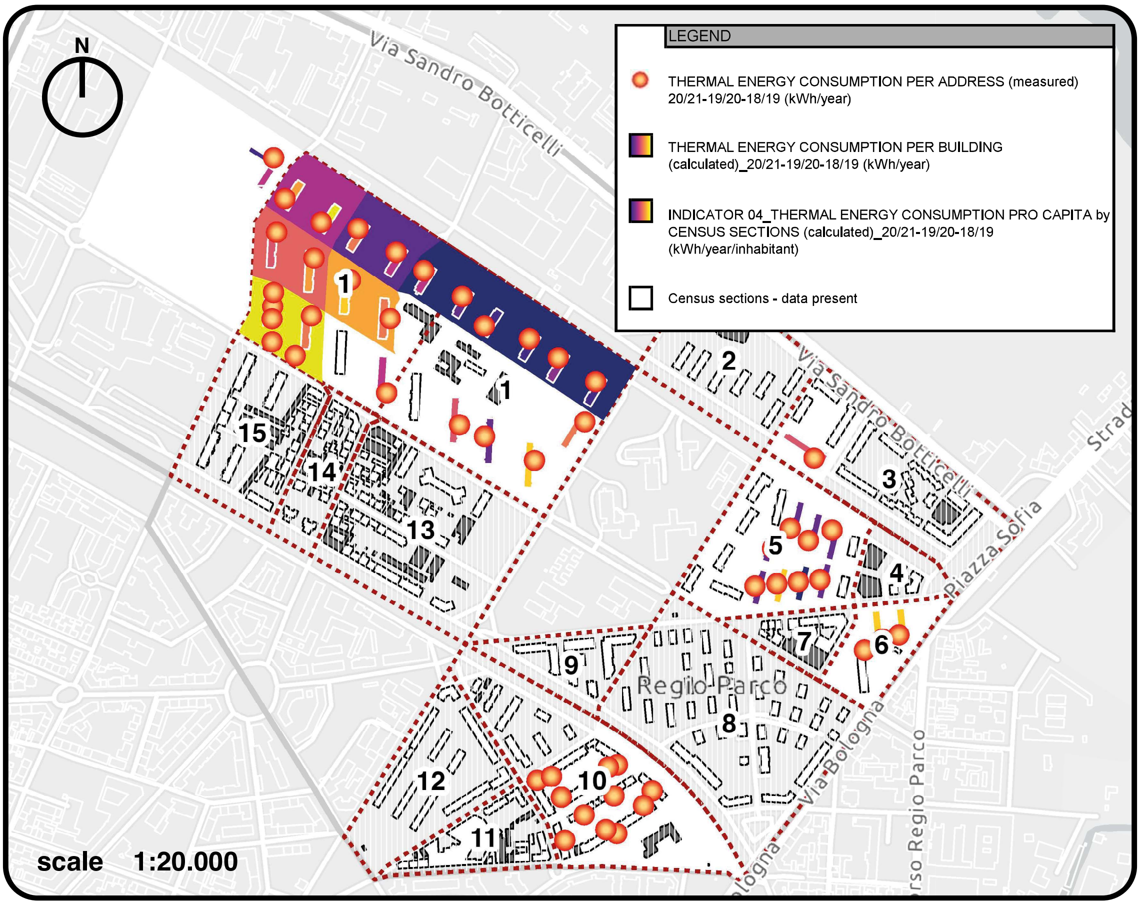


Fig. 33:

Extract of the calculation of the INDICATOR 04: the calculation of per capita thermal energy consumption

(own elaboration, made with ArcGis Pro software)

Given the incomplete nature of the previous calculation, due to the lack of data to estimate the indicator for all the census sections related to the chosen M.U., it has been conducted a further analysis utilizing data from established research literature, with specific reference to the Turin case study examined in chapter 02.

Using this data, it is possible to calculate the estimated Total Energy (Thermal/Electrical) Requirements for each Metabolic Unit.

DATA ACQUISITION:

The “Indicator 3/4” methodology and its associated values, as documented by Pignatelli et al. (2023).

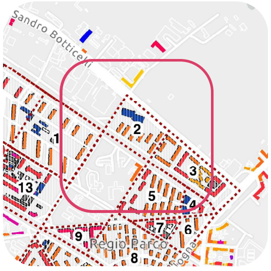


Fig. 34:
Example of the projection of the layers in a M.U.

(source: own elaboration)

CALCULATION METHODOLOGY:

INDICATOR 04: Total Energy (Thermal/Electrical) Requirements for each M.U.

1. **Associate data to each residential building present in the M.U.s:**
    - Disaggregate the residential buildings from the other typologies of buildings.
    - Associate the “Average Annual Consumption Value” for thermal energy calculated in literature (89 kWh/m2/year) to the residential buildings.
    - Associate the “Average Annual Consumption Value” for electric energy calculated in literature (31 kWh/m2/year) to the residential buildings.
2. **Calculate the total thermal and electric energy requirements of each M.U.:**
    - Geoprocessing “**Spatial Join**” between the M.U.s and the residential buildings to have the number of buildings present in each U.M..
    - Calculate the **Total Thermal and Electric Energy Requirements**, multiplying the number of buildings in each M.U. to the “Average Annual Consumption Value” for both of the values.
    - Add the resulting values to the M.U.s. and show them in a choroplet map with their relative values.

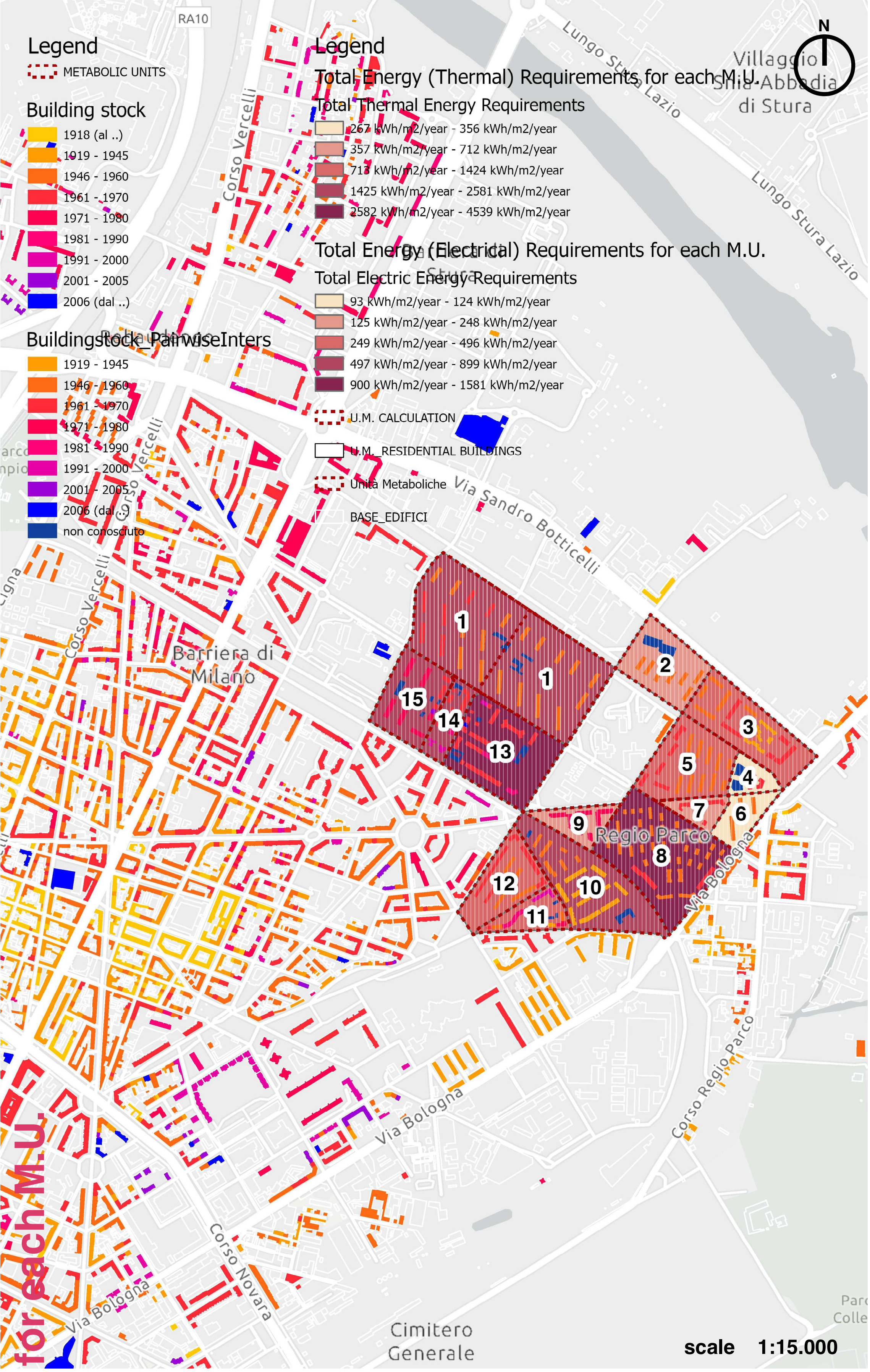
To enhance the robustness of the evaluation, the following complementary calculations could be considered:

- **Evaluate the M.U.s:** Classify the M.U.s as: **“High Efficiency”/ “Low Efficiency”** using this thresholds (defined from APE energetic classes).

FINAL CONSIDERATIONS: Note that the buildings in this area belong to an older building stock, mostly built before the 1980s. The “Average Annual Consumption Values” calculated in the literature were based on the entire building stock of Turin. This explains the high average energy consumption values (kWh/m²) observed during analysis.

CARTOGRAPHIC OUTPUT

INDICATOR 04_Total Energy (Thermal/Electrical) Requirements for each M.U.



Indicator 04_Per capita thermal/electric energy consumption (possible methodology)

OBJECTIVE (of the new possible calculation of the indicator):

The objective is to **estimate the annual electricity and thermal energy consumption per capita for each 'Metabolic Unit' (M.U.)**, in order to evaluate energy performance at the neighborhood level.

This **"demand-centric"** approach assesses how well each M.U. performs in terms of energy consumption, allowing for the identification of M.U.s with high consumption that may require improvements. It directly contributes to **decarbonization efforts** by monitoring energy efficiency at the local level.

EVALUATION METHODOLOGY:

Calculate the aggregated energy consumption *within the boundaries of each M.U.* and then normalize it by the resident population of the M.U.

This allows for a detailed analysis at the neighborhood scale and can be used to **compare M.U.s** and to **evaluate the effectiveness of local policies** aimed at reducing energy consumption or redistributing the energy mix.

CALCULATION METHODOLOGY:

INDICATOR 04: Per capita electricity and thermal energy consumption by M.U.

This indicator quantifies the annual electricity and thermal energy consumption per resident within each Metabolic Unit.

1. **Acquire and spatialize energy consumption data:**
    - **Project raw data** on electricity and thermal energy consumption from service providers. These data are often alphanumeric and not immediately georeferenced.
    - **Connect consumption data to spatial datasets:** Use common identifiers (e.g., addresses, cadastral IDs) to link consumption data (typically in tabular format) to GIS layers of buildings or specific delivery points within the city.

It is important to disaggregate by sector of activity (e.g., residential, industrial) if possible. This step is crucial for assigning consumption to M.U.s.

2. **Prepare the Metabolic Units Layer with Population:**
    - Ensure that each M.U. layer has as a field the **total number of residents**.
3. **Aggregate energy consumption by Metabolic Unit:**
    - Perform a **Spatial Join** in ArcGIS Pro to associate the energy consumption of georeferenced buildings/delivery

points to each M.U.

    - For each M.U., **sum the total electricity consumption** of all buildings/delivery points that fall within its boundaries.
    - For each M.U., **sum the total thermal energy consumption** of all buildings/delivery points that fall within its boundaries.

4. **Calculate Per Capita Consumption by M.U.:**
    - For **Per Capita Electricity Consumption by M.U.**: Divide the total electricity consumption of each M.U. (calculated in step 3) by the total number of residents in that same M.U.
    - For **Per Capita Thermal Energy Consumption by M.U.**: Divide the total thermal energy consumption of each M.U. (calculated in step 3) by the total number of residents in that same M.U.

To enhance the robustness of the evaluation, the following complementary calculations could be considered:

- **Evaluate the M.U.s:**
    - Define **thresholds or benchmarks** to classify the consumption level:
        - Classify the M.U.s as:
            - **“High Efficiency”:** Per capita consumption below a defined threshold.
            - **“To Be Improved”:** Per capita consumption above a defined threshold, indicating possible energy efficiency issues, perhaps due to obsolete building stock or high renovation costs.

Cartographic Outputs:

- **Choropleth maps by M.U.:** Two distinct maps (one for electricity, one for thermal energy) that visually represent the **Per Capita Consumption** for each Metabolic Unit, using a color gradient to indicate different consumption levels (e.g., from lowest to highest, or “High Efficiency” vs. “To Be Improved”).
- These maps can **highlight areas with high energy consumption** and help **simulate the effect of planned energy efficiency interventions**, contributing to progress monitoring.

4.1.4 Other indicators: proposed methodology

Regarding the other indicators listed in the Selected Indicators section of this methodology, it is proposed to use the existing cartography created for the Moloc project in Turin by Pignatelli et al. as a base layer for analysis.

The following example demonstrates a possible methodology for one of the proposed indicators.

Indicator 03_Public transport accessibility

OBJECTIVE:

The objective is to **estimate the level of accessibility to public transport service of each 'Metabolic Unit' (M.U.)** considering the presence of **at least one public transport service per type (bus, tram, metro, and train)**, accessible within a **walking distance of 400 meters (8 minutes)** from the center of each M.U. This indicator aims to assess the equity and connectivity of transport within neighborhood boundaries, contributing to **improving urban livability and ensuring equitable access to resources and opportunities**.

EVALUATION METHODOLOGY:

This methodology shifts the focus of calculation from the service to the **centroid of the metabolic unit, making the indicator "demand-centric"** (measuring how well each M.U. is served) rather than "supply-centric" (which merely counts residents within service buffers).

The analysis allows assessment of M.U.s' level of access to different types of public transport services, which is crucial for **improving urban livability and ensuring equitable access to resources and opportunities**. Monitoring results can be used to **compare cities and simulate the effect of planned investments or network performance improvements**.

It also contributes to **decarbonization efforts by encouraging the shift to public transport**, reducing dependence on private vehicles and lowering CO2 emissions.

DATA ACQUISITION:

"Indicator 2" ArcGis Pro map layers, from Pignatelli et al., 2023.

CALCULATION METHODOLOGY:

INDICATOR 03: Level of accessibility of M.U.s to public transport services (count of distinct service types within 400m/8min walking distance).

1. **Define accessibility zones based on walking distance for each M.U. centroid:**
    - For each Metabolic Unit, calculate from its centroid the area reachable on foot within **8 minutes (approximately 400 meters)**.

    - The selected tool is the **ORS Tools Plugin for QGIS**, which connects to OpenRouteService via an API (Application Programming Interface).

2. **Filter public transport services by type and frequency:**
    - Project all public transport stops (bus, tram, metro, train).
3. **Count accessible service types for each M.U.:**
    - For each M.U. isochrone count the **number of distinct types of public transport services** (bus, tram, metro, train) that have at least one qualified stop within the 8-minute walking distance.
    - If **types ≥ 1** ⇒ M.U. is "served" (=1), otherwise 0.

Prerequisites:

- Layer **M.U.** (polygons) with field Total number of residents for M.U. (or associated population).
- Layer **Public Transport Services** (points) with field type (bus, tram, metro, train).

CALCULATION STEPS (based on ArcGIS Pro / QGIS):

1. **M.U. Centroid:**
    - Geoprocessing Tool: **Feature To Point** of each Metabolic Unit → creates UM_centroids
2. **Walking Isochrones:**
        - **Pedestrian Isochrones:**
    - Use ORS Tools Plugin in QGIS to create **isochrones** based on walking distance starting from the centroids of the Metabolic Units.
        1. In the **Processing Toolbox**, search for:
            - ORS Tools → Isochrones → Isochrones from Point-Layer.
        2. Set the parameters:
            - **Centroid layer.**
            - **Travel mode**: *foot-walking.*
            - **Range type**: time (minutes).
            - **Range**: 8
        3. Click *Run* → QGIS generates polygons of areas reachable within 8 minutes on foot.
3. **Prepare the Public Transport Services Layer:**
    - **Project** on ArcGis Pro the layers related to the public transport stop locations per types (bus, tram, metro, train).
    - Create a new layer of PUBLIC TRANSPORT SERVICES to

use just for calculation of the indicators.

        1. Add the **field** type to each layer related to PUBLIC TRANSPORT SERVICES specifying which kind of service represents that layer.
        2. Geoprocessing **“Merge”** to create different layers, according to their feature type (polygon or point) containing all the features of the basic services.
        3. Geoprocessing **“Feature to Point”** to transform the polygons layers associated to the services into point layers.
        4. Geoprocessing **“Merge”** to create an aggregated layer containing all the services points: PTS_points_merge

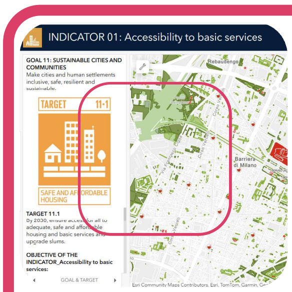
    - **Geoprocessing Spatial Join**: Public Transport Service_ Areas_10min ⟵ Public Transport.
        1. Geoprocessing **Intersect** each U.M. ISOCHRONE layer with the layer of the points containing the public transport services. This will associate each accessible public transport stop with the M.U. isochrone in which it falls.
        2. Geoprocessing **Summary Statistics** for the layers of the intersection: Statistics = COUNT by type.
    - Result: For each **M.U.**, a count representing the number of distinct types of public transport service (bus, tram, metro, train) accessible within 8 minutes.

4. **Calculate the Accessibility Level:**
    - Export the data and use an Excel table to calculate the quantity of each main typology of public transport service (**bus, tram, metro, and train**) for each M.U.; if not, the M.U. is considered ‘To be improved’.
    - Assign an “Accessibility Level” to each M.U. based on the count of distinct service types:
        1. **Level 4 (High):** All 4 types (bus, tram, metro, train) are accessible.
        2. **Level 3:** 3 types are accessible.
        3. **Level 2:** 2 types are accessible.
        4. **Level 1:** 1 type is accessible.
        5. **Level 0 (Low):** No type of public transport service is accessible according to the defined criteria.

Cartographic Outputs:

- **Choropleth map for M.U.:**
    - **Accessibility Level** (0-4) for each Metabolic Unit.

4.2 Dashboard Prototype


INDICATOR 01: Accessibility to basic services

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES
Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11.1
By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

OBJECTIVE OF THE INDICATOR_Accessibility to basic services:

Fig. 36:
Example of a Indicator Dashboard for the Dashboard Prototype

(source: own elaboration)

A dashboard prototype was developed using **ArcGIS Dashboards**, an **interactive, storytelling web-based system.**
The dashboard is explicitly designed to monitor a crucial set of Sustainable Development Goals (SDGs) indicators at the neighbourhood scale (Pignatelli et al., 2023).

This prototype aims to support decision-makers in developing sustainable urban planning strategies and fostering co-creation for future urban transformations through clear, spatialized outputs (Pignatelli et al., 2023).

The core design principles of a dashboard are centered on **facilitating participative processes** and engaging stakeholders in collaborative planning, offering comprehensive visualization capabilities for informed decision-making (Pignatelli et al., 2023).

The prototype is thinked to specifically visualize the indicators selected, crucial for neighborhood-scale sustainability assessment:

- **Accessibility metrics**: This category includes the percentage of the population capable of reaching basic public services within a 10-minute walk, the availability and accessibility of green areas (including the percentage of the population without access within a 6-minute walk), and public transport accessibility based on service frequency and ease of reaching stops.
- **Energy consumption indicators**: This includes per capita electricity consumption and per capita thermal energy consumption, both measuring domestic energy use.
- **Environmental quality metrics**: This encompasses per capita urban solid waste produced (in kg/year), the population exposed to high concentrations of PM10/2.5, the quality of green spaces (quantified by the NDVI index in sqm), and the impact of tree cover on local microclimate management through temperature reduction.

In terms of visualization techniques, the prototype leverages a **multidisciplinary GIS-based framework** for the spatial evaluation of these indicators, integrating large datasets to achieve high realism and detail (Pignatelli et al., 2023).

Key methods include creating **thematic maps**, particularly choropleth maps, to display the distribution of results and identify hotspots or areas needing improvement (Pignatelli et al., 2023).

The assessment of accessibility to basic services and green areas utilizes **isochrones** to define “liveable areas,” mapping regions where essential amenities are accessible within specified walking distances, such as a 6-minute (300m) or 10-minute walk (Wang et et al., 2024). This granular approach is critical for localized sustainability assessments and revealing patterns of urban accessibility (Wang et al., 2024).

From a user interface perspective, the prototype, built with ArcGIS Dashboards, is thinked for **intuitive and interactive visualizations**, combining maps, charts, and tables to present complex information comprehensively (Pluto-Kossakowska et al., 2022).

The goal is to ensure a **clear and understandable visualization of results**, making the tool accessible to both non-expert users seeking general awareness and specialists requiring in-depth analysis for urban planning (Pignatelli et al., 2023). This user-centric design is crucial for extracting meaningful insights and fostering data-driven decision-making (Delfini et al., 2024).

The integration of georeferenced data is foundational to the prototype, with indicators systematically evaluated and spatialized across the entire municipal area using GIS tools (Pignatelli et al., 2023).

This process involves harmonizing geometric information with alphanumeric values sourced from various data streams, such as energy consumption records, green area shapefiles, and points of interest for public facilities (Pignatelli et al., 2023).

For example, energy consumption data, often initially alphanumeric, are connected to spatial datasets using common identifiers and aggregated by "Metabolic Units" (M.U.s) using **Spatial Join in ArcGIS Pro** to calculate per capita consumption. Similarly, the ORS Tools Plugin for QGIS is used to create walking **isochrones** from M.U. centroids for accessibility analyses, projecting and counting service types or green spaces within these buffers.

This robust georeferencing enhances the management, analysis, and visualization of extensive datasets, uncovering spatial relationships that are vital for targeted, data-driven suggestions for local development planning (Pignatelli et al., 2023). Link to the dashboard prototype: https://www.arcgis.com/apps/dashboards/79ace57b53b54c4fbdc5ecb3d87e0a3d


INDICATOR 01: Accessibility to basic services

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES
Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11.1
By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

OBJECTIVE OF THE INDICATOR_Accessibility to basic services:

LEGEND:

01_ACCESSIBILITY TO BASIC SERVICES by M.U.

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES BY M.U.

- 🟩 SERVED (ACCESSIBILITY TO BASIC SERVICES ≥ 3)
- 🟥 TO BE IMPROVED (ACCESSIBILITY TO BASIC SERVICES < 3)

METABOLIC UNITS_LAYER

BUILDINGS divided by M.U.

Categoria d'uso

- ◣
- ◣ Non conosciuto
- ◺ abitativa
- ◣ altro
- ◣ commerciale
- ◣ industriale
- ◣ luogo di culto

Fig. 37:

Visualization of a page of the ArcGis Dashboard prototype.

(own elaboration, made with ArcGis Dashboard)

Pop-up menu with

Information about the map:

Indicator 01_Accessibility to basic services:

Score of M.U. accessibility to basic services (access to at least 3 key services within a 10-minute walk from the center of the M.U.).

Choropleth map by M.U.:
- Served (if types ≥ 3)/To be improved (if types < 3);
- Other layers fundamental for the calculation of the indicator;
- Hidden layers fundamental for the calculation (that can be visualized using the pull down menu on the right).

Other information about the Indicator: Objective and Methodology

Pop-up menu with

Information about the linked

SDGs: SDGs interlinkages visualization tool QR Code.

Legend of the INDICATOR:

All the layers are here shown to help the navigation of the choropleth map.
The map has all the layers that were needed for the calculation of the indicators.
The other indicators can be visualized by sliding the divider at the right of the legend to the centre.

ELEMENTS OF THE DASHBOARD

4.3 Discussion

The deployment of web-based dashboard prototypes for monitoring Sustainable Development Goals (SDGs) at the neighbourhood scale represents a **significant advancement in urban sustainability efforts**, fundamentally reshaping how global objectives are translated into actionable local strategies.

These platforms serve as **invaluable instruments for enhancing transparency in governance and promoting sustainable urban development**, particularly acknowledging the pivotal role of cities and their neighbourhoods in addressing local social, economic, and environmental challenges within the 2030 Agenda (Pignatelli et al., 2023).

By effectively converting abstract sustainability goals into practical, implementable strategies customized to local contexts, these dashboards support evidence-based decision-making and encourage robust stakeholder participation in collaborative planning processes.

Comparison with Similar Initiatives

An analysis of the Turin prototype alongside similar initiatives reveals **shared methodologies and potential areas for enhancement**.

The Turin prototype's **focus on user-centered design and interactive visualizations complements approaches seen in platforms like the Dublin Dashboard**, which utilized "stories" to make complex data more accessible to non-experts (Pluto-Kossakowska et al., 2022).

Similarly, in terms of **achieving highly detailed spatial analysis, the Turin prototype's use of "Metabolic Units" (based on census sections) for precise geographical insights parallels DATA2GO.NYC's granular data presentation down to individual census tracts** (United Nations Statistics Division, 2020).

Furthermore, the **incorporation of accessibility metrics through isochrone mapping in Turin reflects similar advanced geospatial analytics seen in studies like that for Hamilton, New Zealand**, which evaluates the "15-minute city" concept by mapping walkable access to essential services (Wang et al., 2024).

Strengths of the Approach

The dashboard prototype exhibits several notable advantages in neighbourhood-scale SDG monitoring.

Its **demand-oriented evaluation methodology** moves beyond simple service counting to assess actual service coverage per Metabolic Unit, providing more accurate and contextually relevant accessibility measurements (Pignatelli et al., 2023).

The **multidisciplinary Geographic Information System (GIS) framework** enables the seamless integration of diverse datasets with high precision, which is essential for comprehensive spatial analysis and effectively identifying urban strengths and weaknesses within neighbourhoods (Pignatelli et al., 2023).

Moreover, the **incorporation of empirical urban-scale data ensures that policy decisions are grounded in concrete evidence**, thereby significantly enhancing the reliability of sustainability assessments (Pignatelli et al., 2023). Additionally, the **flexible methodological framework permits adaptation to specific territorial characteristics and priorities**, enhancing its applicability across various urban settings and supporting localized solutions (Siragusa et al., 2021).

Limitations of the Approach

Despite its strengths, the implementation of web-based dashboards for neighbourhood SDG monitoring, including the Regio Parco prototype, presents certain inherent challenges.

A primary concern involves the **availability and quality of granular data at sub-national levels**, often compromised by fragmented sources, outdated public datasets, and privacy considerations that necessitate the use of aggregated information (Pignatelli et al., 2023).

Dependence on static data sources without regular updates creates significant data relevance issues, potentially rendering analytical models obsolete and hindering real-time responsiveness (United Nations Statistics Division, 2020).

Additionally, many current SDG indicators often **lack specific neighbourhood-level relevance**, failing to capture the nuanced local dynamics and context-specific challenges beyond general environmental factors (Pulgar Rubilar et al., 2023).

Despite efforts to simplify interfaces, the **technical sophistication required by these platforms may limit accessibility for general users**, making them more suitable for specialists than for broader public engagement (Pluto-Kossakowska et al., 2022).

A fundamental conceptual issue also persists in the **absence of standardized neighbourhood definitions**, which can lead to measurement inconsistencies that distort assessments and obscure local disparities, complicating cross-neighbourhood comparisons (Simon et al., 2016).

Furthermore, **insufficient local governance capacity and inadequate stakeholder engagement** often present significant barriers to effective implementation and community participation at the neighbourhood scale (Alonso Frank & Mattioli, 2023).

Future Improvements and Applications

For future development, enhancements and applications of neighbourhood-scale SDG dashboard prototypes should focus on several key areas.

Integrating real-time data from various sensors and meters would provide ongoing, dynamic insights into urban systems, enabling more responsive and proactive approaches to urban challenges, as demonstrated by platforms such as Eindhoven in Cijfers (Katmada et al., 2023).

Additional focus should be placed on **optimizing planning processes and developing inclusive accessibility features** to ensure that information is readily accessible to all stakeholders, including non-specialists and individuals with disabilities (Pluto-Kossakowska et al., 2022).

The existing adaptable framework within these dashboards supports **comparative analysis and benchmarking of sustainability progress across regions**, thereby facilitating knowledge exchange and the implementation of best practices globally (Wang et al., 2024).

Furthermore, promoting **enhanced participatory governance by directly involving communities in defining priorities and co-creating strategies** would strengthen local ownership and legitimacy, effectively bridging the gap between policy directives and community needs (Trane et al., 2023).

Continued efforts to **address fundamental data limitations and methodological inconsistencies at the neighbourhood level** remain essential for maintaining the effectiveness and utility of these crucial urban planning tools (Oxoli et al., 2023).

CONCLUSIONS

This thesis presented the **development of a web-based dashboard prototype** specifically designed to visualize and assess Sustainable Development Goal (SDG) indicators at the neighborhood scale, addressing a critical gap in localizing global sustainability objectives.

A core contribution is the establishment of a **demand-centric evaluation methodology** for indicators, shifting the analytical focus from merely counting services to assessing how effectively each "Metabolic Unit" (M.U.)—defined by aggregated census sections—is served, thus providing more accurate and contextually relevant insights into neighborhood conditions.

The prototype, built using ArcGIS Dashboards and leveraging ArcGIS Pro and QGIS tools, systematically integrates diverse georeferenced data through the calculation of its indicators and aims to include, in a future, **eight key indicators,** to calculate nine key indicators spanning accessibility to basic services, green areas, and public transport, alongside per capita energy consumption, waste production, air quality, green quality, and tree cover for microclimate management. This multidisciplinary GIS-based framework ensures high precision in spatial analysis and the effective identification of urban strengths and weaknesses at a granular level.

The relevance of this work for urban sustainability and planning is significant, particularly in the context of the 2030 Agenda, which recognizes the pivotal role of cities and their neighborhoods in confronting complex social, economic, and environmental challenges.

By transforming abstract global goals into practical, locally tailored strategies, the dashboard prototype **supports evidence-based decision-making** and promotes transparent governance, ensuring that policy interventions are grounded in concrete data rather than assumptions.
Its user-centered design and interactive visualizations are intended to facilitate participative processes, encouraging broader stakeholder engagement and collaborative planning essential for resilient urban transformations.

Furthermore, the flexible methodological framework enhances its applicability, allowing for adaptation to diverse territorial characteristics and priorities across various urban settings.

Looking ahead, **several key directions for future research and improvements** emerge to further enhance the utility and impact of such neighborhood-scale SDG dashboards:

- **Integration of real-time data**: Future efforts should focus on seamlessly integrating dynamic data from various sensors and meters to provide continuous, up-to-the-minute insights into urban systems, enabling more responsive and proactive approaches to challenges (Katmada et al., 2023).
- **Optimization of planning processes and inclusive accessibility**: It is crucial to optimize existing planning processes and develop inclusive accessibility features, ensuring the dashboard's information is readily accessible to all stakeholders, including non-specialists and individuals with disabilities (Pluto-Kossakowska et al., 2022).
- **Addressing data limitations and methodological inconsistencies**: Continued efforts are essential to overcome fundamental data challenges at granular levels, such as fragmented sources, outdated public datasets, privacy concerns, and the need for higher spatial resolution (United Nations Statistics Division, 2020).
- **Standardization of neighborhood definitions**: A conceptual issue concerning the absence of standardized neighborhood definitions must be addressed to mitigate measurement inconsistencies that can distort assessments and obscure local disparities, hindering cross-neighborhood comparisons (Simon et al., 2016).
- **Enhanced participatory governance**: Promoting deeper community involvement in defining priorities and co-creating strategies is vital to strengthen local ownership and legitimacy, effectively bridging the gap between top-down policy directives and bottom-up community needs (Trane et al., 2023).
- **Facilitating comparative analysis and benchmarking**: The adaptable framework

already in place should be leveraged to support comparative analysis and benchmarking of sustainability progress across different regions, fostering knowledge exchange and the implementation of best practices globally (Wang et al., 2024).

Ultimately, the development of this prototype serves as a foundational step toward more nuanced, data-driven, and inclusive urban planning, underscoring the enduring potential of digital tools to foster truly sustainable and equitable cities for all.

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ANNEX

TABLE 3:INDICATORS'S SPECIFICS

TABLE 3: Selected indicators and their correspondence with SDGs

indicator	Descrizione indicatore	unit of measurement	Goal (SDGs)	Target (SDGs)	Indicatore (SDGs)
ACCESSIBILITY TO BASIC SERVICES	Percentage of population that can reach basic public services (divided by type) with a distance that can be covered in 10 minutes on foot.	%	11 SUSTAINABLE CITIES AND COMMUNITIES	**Target 11.1:** By 2030, ensure access to adequate, safe and affordable housing and basic services and the modernization of poor neighborhoods for all.	/
AVAILABILITY AND ACCESSIBILITY OF GREEN AREAS	The indicator describes the availability of green areas per inhabitant and the percentage of the population that does not have access to green areas within a distance that can be covered in 10 minutes on foot.	%	11 SUSTAINABLE CITIES AND COMMUNITIES	**Target 11.7:** By 2030, provide universal access to safe, inclusive and accessible public green spaces, particularly for women and children, the elderly and people with disabilities.	/
ACCESSIBILITY PUBLIC TRANSPORT	The indicator estimates the percentage of population living in a defined area that has access to a specific level of public transport service The indicator is based on the frequency of service with the simplicity of reaching stops.	%	11 SUSTAINABLE CITIES AND COMMUNITIES	**Target 11.2:** By 2030, provide access to safe, sustainable, and affordable transportation systems for all, improve road safety, (...).	**Indicator 11.2.1**
ELECTRICITY CONSUMPTION PER CAPITA	The indicator provides information on per capita domestic energy consumption and is based on per capita electricity expenditure.	kWh/abitante	7 AFFORDABLE AND CLEAN ENERGY	**Target 7.2:** By 2030, significantly increase the share of renewable energy in the global energy mix.	/
CONSUMPTION OF THERMAL ENERGY PER CAPITA	The indicator provides information on per capita domestic energy consumption and is based on per capita gas expenditure.	kWh/abitante	7 AFFORDABLE AND CLEAN ENERGY	**Target 7.2:** By 2030, significantly increase the share of renewable energy in the global energy mix.	/
MUNICIPAL SOLID WASTE PRODUCTS PER CAPITA	The indicator describes the waste collected per capita in a year expressed in kg.	kg/abitante	11 SUSTAINABLE CITIES AND COMMUNITIES	**Target 11.6:** By 2030, reduce the negative environmental impact of cities per capita, in particular regarding air quality and waste management.	**Indicator 11.6.1**
POPULATION EXPOSED TO PM10/2.5	The indicator measures the number of population exposed to high concentrations of PM2.5/PM10.	%	11 SUSTAINABLE CITIES AND COMMUNITIES	**Target 11.6:** By 2030, reduce the negative environmental impact of cities per capita, in particular regarding air quality and waste management.	**Indicator 11.6.2**
GREEN QUALITY	The indicator provides the total amount of green area in m2 through the NDVI index based on satellite images.	mq	15 LIFE ON LAND	/	/
TREE-LINED ROOF FOR MANAGING THE LOCAL MICROCLIMATE	The indicator measures the reduction of ambient temperature through evapo-transpiration and shading	%	15 LIFE ON LAND	/	/

source: own elaboration

CALCULATION TABLES:

TABLE 1: Census sections basic data

Identification number Census Section	Number of residents	Number of families	Area *(sqm)*
2671	207	80	9371
2672	238	81	10044
2673	564	258	45426
2674	704	231	27994
3606	209	77	9870
3607	222	79	8410
3608	223	114	10008
3609	217	72	9613
2825	362	179	32208
1732	845	402	30152
3325	292	118	12175
3604	127	81	9690
1735	881	391	38699
3605	424	190	14005
2666	179	83	9784
1743	676	344	68694
2827	356	163	14701
1740	226	119	11267
1742	241	138	25943
2826	295	140	17324
1741	415	198	15917
1739	780	351	29923
1774	332	163	22832
3333	485	220	30645
3332	213	106	14053
1773	508	255	32690

source: own elaboration

source: own elaboration

**TABLE 2: Basic data transformation:
Aggregation of census sections into "Metabolic Units"**

Identification number Census Section	Metabolic Unit
2671	**1**
2672	
2673	
2674	
3606	
3607	
3608	
3609	
2825	**2**
1732	**3**
3325	
3604	**4**
1735	**5**
3605	**6**
2666	**7**
1743	**8**
2827	**9**
1740	**10**
1742	
2826	
1741	**11**

TABLE 3: Calculation of aggregate data by metabolic unit

Metabolic Unit	Number of residents - total per m.u.	Number of families - total per m.u.	Area - total per m.u. (sqm)
1	2584	992	130736
2	362	179	32208
3	1137	520	42327
4	127	81	9690
5	881	391	38699
6	424	190	14005
7	179	83	9784
8	676	344	68694
9	356	163	14701
10	762	397	54534
11	415	198	15917
12	780	351	29923
13	817	383	53476
14	213	106	14053
15	508	255	32690

source: own elaboration

TABLE 4: Calculations on um useful for statistics

Metabolic Unit	Number of residents /hectare	Number of households /hectare	Total area: sum of areas m.u. (sqm)	% Area (sum of m.u. areas)
1	0.02	0.01	561437	23%
2	0.01	0.01		6%
3	0.03	0.01		8%
4	0.01	0.01		2%
5	0.02	0.01		7%
6	0.03	0.01		2%
7	0.02	0.01		2%
8	0.01	0.01		12%
9	0.02	0.01		3%
10	0.01	0.01		10%
11	0.03	0.01		3%
12	0.03	0.01		5%
13	0.02	0.01		10%
14	0.02	0.01		3%
15	0.02	0.01		6%

source: own elaboration

CALCULATION TABLES:

INDICATOR 01:

Tables for the calculation of the count of the basic services in each M.U.

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES (SERVICE COUNT PER M.U.)	1	2	3	4	5	6	7	8
EDUCATION FACILITIES								
SCHOOL	7	3	6	8	6	8	8	8
UNIVERSITIES	0	0	0	0	0	0	0	0
OTHER AREAS OF COMMON INTEREST FACILITIES								
CHURCHES	2	2	3	3	3	4	4	4
OTHER RELIGIONS	1	0	0	0	0	0	0	0
LIBRARIES	0	0	0	0	0	0	0	0
SSA	0	1	2	2	2	4	3	4
MARKETS	1	0	0	0	0	0	0	0
SPORT FACILITIES	0	0	0	0	0	0	0	0
CONTROLLED ACCESS PARKING	0	1	1	1	1	1	1	1
PARKING SPACES FOR DISABILITIES	12	7	12	12	11	11	12	13
FOOD MARKETS	37	22	21	23	21	21	34	36
OTHER SHOPS	69	44	52	53	47	52	61	71
NON-FOOD SHOPS	168	85	92	94	79	89	125	141
MIXED SHOPS	48	32	29	34	31	34	50	56
HEALTHCARE FACILITIES								
HOSPITAL	2	0	0	0	0	0	0	0
PHARMACY	4	1	1	1	1	1	2	2
PUBLIC GREEN SPACES								
GREEN_OTHER	1	16	12	9	4	10	6	2
GREEN URBAN AREAS	1027	892	1069	1110	900	1106	1171	1163

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES (SERVICE COUNT PER M.U.)	9	10	11	12	13	14	15
EDUCATION FACILITIES							
SCHOOL	14	16	16	16	13	10	11
UNIVERSITIES	0	0	0	0	0	0	0
OTHER AREAS OF COMMON INTEREST FACILITIES							
CHURCHES	5	3	3	4	4	4	3
OTHER RELIGIONS	2	2	2	2	2	2	2
LIBRARIES	0	0	0	0	0	0	0
SSA	4	4	4	4	4	3	3
MARKETS	1	0	0	0	1	0	0
SPORT FACILITIES	0	0	0	0	0	0	0
CONTROLLED ACCESS PARKING	0	0	0	0	0	0	0
PARKING SPACES FOR DISABILITIES	16	15	15	15	16	15	16
FOOD MARKETS	43	39	39	38	45	60	65
OTHER SHOPS	89	81	81	76	94	96	105
NON-FOOD SHOPS	169	169	169	147	181	210	246
MIXED SHOPS	61	59	59	53	56	69	88
HEALTHCARE FACILITIES							
HOSPITAL	2	0	0	0	2	2	2
PHARMACY	3	4	4	4	3	6	6
PUBLIC GREEN SPACES							
GREEN_OTHER	3	0	0	0	2	0	0
GREEN URBAN AREAS	1413	1077	1077	1084	1429	1239	989

source: own elaboration

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES (SERVICE COUNT PER M.U.)	SUM M.U. 1	SUM M.U. 2	SUM M.U. 3	SUM M.U. 4	SUM M.U. 5	SUM M.U. 6	SUM M.U. 7	SUM M.U. 8
EDUCATION FACILITIES	7	3	6	8	6	8	8	8
OTHER AREAS OF COMMON INTEREST FACILITIES	338	194	212	222	195	216	290	326
HEALTHCARE FACILITIES	6	1	1	1	1	1	2	2
PUBLIC GREEN SPACES	1028	908	1081	1119	904	1116	1177	1165

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES (SERVICE COUNT PER M.U.)	SUM M.U. 9	SUM M.U. 10	SUM M.U. 11	SUM M.U. 12	SUM M.U. 13	SUM M.U. 14	SUM M.U. 15
EDUCATION FACILITIES	14	16	16	16	13	10	11
OTHER AREAS OF COMMON INTEREST FACILITIES	390	372	372	339	403	459	528
HEALTHCARE FACILITIES	5	4	4	4	5	8	8
PUBLIC GREEN SPACES	1416	1077	1077	1084	1431	1239	989

M.U.	ACCESSIBILITY LEVEL
1	SERVED
2	TO BE IMPROVED
3	TO BE IMPROVED
4	TO BE IMPROVED
5	TO BE IMPROVED
6	TO BE IMPROVED
7	TO BE IMPROVED
8	TO BE IMPROVED
9	SERVED
10	SERVED
11	SERVED
12	SERVED
13	SERVED
14	SERVED
15	SERVED

source: own elaboration

INDICATOR 02:
Tables for the calculation of the indicator for each M.U.

Metabolic Unit	Area - total per um. (m2) - Area_s_M.U.	TOTAL AREA (sqm) - Area_M.U.	GREEN AREAS FOR UM. TOTAL AREA (sqm) - Area_Veg
1	130736	528747	32056
2	32208		8611
3	42327		5944
4	9690		192
5	38699		9722
6	14005		3283
7	9784		75
8	68694		21536
9	14701		3823
10	54534		8402
11	15917		3124
12	29923		6147
13	53476		5059
14	14053		1782
15	32690		5941

Availability (%) = (Area_Veg / Area_ MU) × 100	Availability for each M.U. (%) = (Area_Veg / Area_s_U.M.) × 100
6	25
2	27
1	14
0	2
2	25
1	23
0	1
4	31
1	26
2	15
1	20
1	21
1	9
0	13
1	18

source: own elaboration

INDICATOR 04:
Tables for the calculation of the Energy consumption per capita, with the data acquired from ATC Torino.

ID BUILDING	SEZ	SEZCENS_00	Street	Civic (referring to measured energy data)	Sub (referring to measured energy data)	Energy consumption (measured) 2020-2021 (kWh/year)
1	3325	SEZCENS_06	CORSO TARANTO	157	/	266390
2	1772	SEZCENS_10	CORSO TARANTO	80	/	915700
3	1772	SEZCENS_10	VIA MERCADANTE SAVERIO	/	/	/
4	3609	SEZCENS_11	CORSO TARANTO	90	scala B	380300
5	3609	SEZCENS_11	VIA MERCADANTE SAVERIO	134		400100
6	2671	SEZCENS_12	VIA CILEA FRANCESCO	11		425700
7	2671	SEZCENS_12	VIA MASCAGNI PIETRO	2	scala A	346200
8	3606	SEZCENS_13	VIA PERGOLESI GIOVANNI BATTISTA	55	scala A; scala B; scala C	442000
9	3606	SEZCENS_13	VIA CILEA FRANCESCO	5		382800
10	2672	SEZCENS_14	VIA CILEA FRANCESCO	14		349500
11	2672	SEZCENS_14	CORSO TARANTO	104	scala A	446400
12	3607	SEZCENS_15	VIA MASCAGNI PIETRO	10	scala A	392700
13	3607	SEZCENS_15	VIA TARTINI GIUSEPPE	41		404120
14	3608	SEZCENS_16	VIA TARTINI GIUSEPPE	31		388300
15	2674	SEZCENS_17	CORSO TARANTO	136	scala A	451100
16	2674	SEZCENS_17	VIA TARTINI GIUSEPPE	46		425800
17	2674	SEZCENS_17	CORSO TARANTO	130	scala A	457800
18	2674	SEZCENS_17	CORSO TARANTO	146	scala A	340700
19	2674	SEZCENS_17	VIA MASCAGNI PIETRO	21	scala B	384500
20	2674	SEZCENS_17	CORSO TARANTO	122	scala B	402200
21	2673	SEZCENS_18	VIA CORELLI ARCANGELO	41		257900
22	2673	SEZCENS_18	VIA PERGOLESI GIOVANNI BATTISTA	105	scala C	288300
23	2673	SEZCENS_18	VIA PERGOLESI GIOVANNI BATTISTA	91	scala B	399400
24	2673	SEZCENS_18	VIA PERGOLESI GIOVANNI BATTISTA	93	scala C	274700
25	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	33	int. 27	2478000
26	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	33	int. 24	2478000
27	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	45	int. 5	2478000
28	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	41	int. 12	2478000
29	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	37	int. 19	2478000
30	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	41	int. 14	2478000
31	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	45	int. 9	2478000
32	1735	SEZCENS_20	VIA CRAVERO GIOVANNI	37	int. 21	2478000
33	3605	SEZCENS_23	VIA BOLOGNA	267	int. 5	1623800
34	3605	SEZCENS_23	VIA BOLOGNA	267	int. 10	1623800
35	3605	SEZCENS_23	VIA BOLOGNA	265	int. 4	1623800

source: own elaboration

Energy consumption (measured) 2019-2020 (kWh/year)	Energy consumption (measured) 2018-2019 (kWh/year)	Civic (referring to the entire building)	Sub	Totale numeri civici per edificio	Estimated energy consumption 2020-2021 (kWh/year)
233100	241050	151; 153; 155; 157		4	1065560
935700	933100	80		1	915700
/	/	137	int. 6/A	1	915700
324300	322300	90	scala A; scala B	2	760600
393200	380000	134; 136		2	800200
393500	380800	7; 9; 11		3	1277100
328900	298100	2	scala A; scala B; scala C	3	1038600
382200	365000	55	scala A; scala B; scala C	3	1326000
387500	371500	1; 3; 5		3	1148400
326200	328300	12; 14		2	699000
399800	388400	104	scala A; scala B	2	892800
363500	353500	10	scala A; scala B; scala C	3	1178100
376850	374630	39; 41; 43		3	1212360
347900	368600	31; 33; 35; 37		4	1553200
376400	377100	136	scala A; scala B	2	902200
373900	357000	44; 46		2	851600
413300	393300	130	scala A; scala B	2	915600
309000	306900	146	scala A; scala B	2	681400
326800	353800	21	scala A; scala B	2	769000
383400	348500	122	scala A; scala B	2	804400
219700	221300	37; 39; 41		3	773700
259600	276300	105	scala A; scala B; scala C; scala D	4	1153200
224800	294000	91	scala A; scala B; scala C; scala D	4	1597600
262800	264000	93	scala A; scala B; scala C; scala D	4	1098800
2301280	2325800	33	int. 26; int. 27; int. 28	3	825999
2301280	2325800	33	int. 23; int. 24; int. 25	3	825999
2301280	2325800	45	int. 5; int. 6; int. 7	3	825999
2301280	2325800	41	int. 11; int. 12; int. 13	3	825999
2301280	2325800	37	int. 18; int. 19	2	550666
2301280	2325800	41	int. 14; int. 15; int. 16	3	825999
2301280	2325800	45	int. 8; int. 9; int. 10	3	825999
2301280	2325800	37	int. 20; int. 21; int. 22	3	825999
1581100	1581100	267	int. 5; int. 6; int. 7	3	1623801
1581100	1581100	267	int. 8; int. 9; int. 10	3	1623801
1581100	1581100	265	int. 1; int. 2; int. 3; int. 4	4	2165068

source: own elaboration

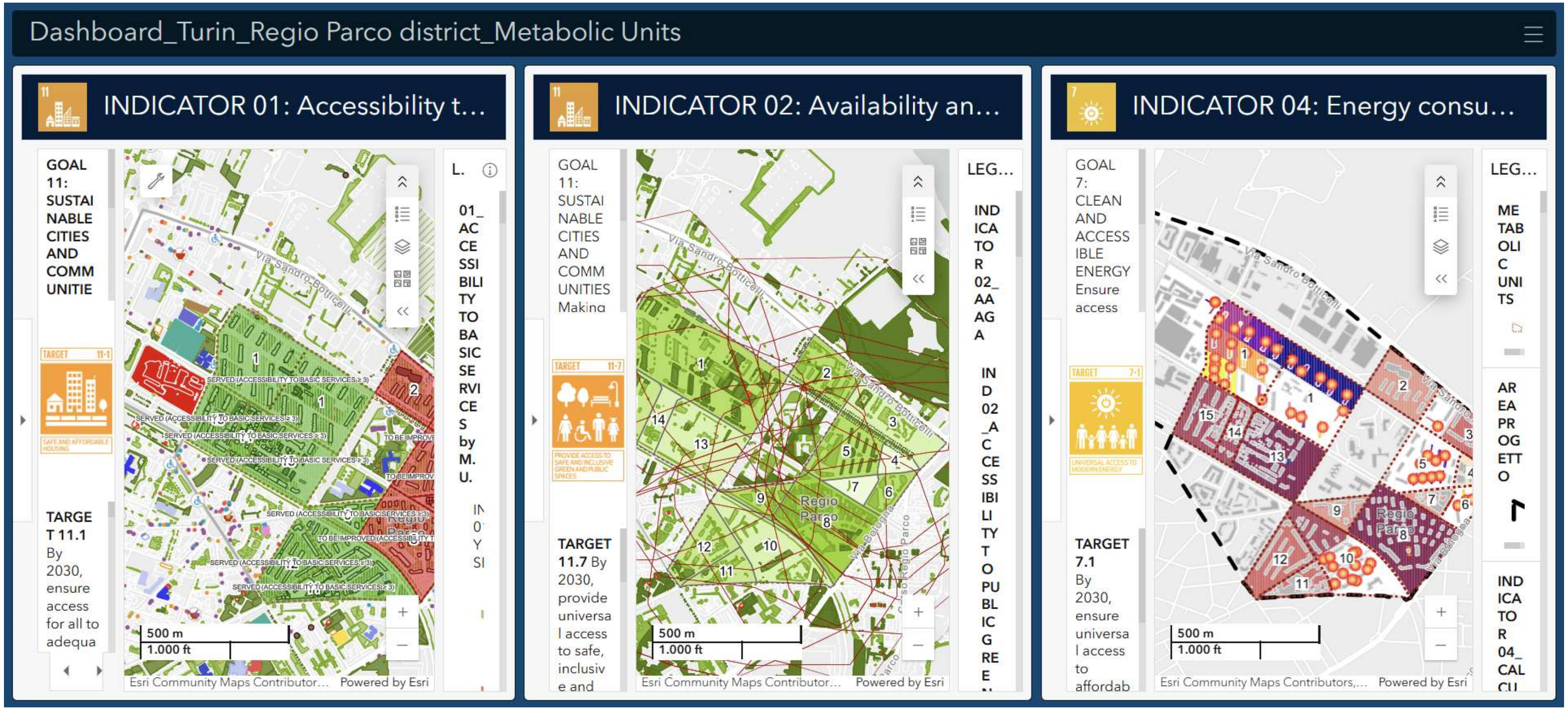
Estimated energy consumption 2019-2020 (kWh/year)	Estimated energy consumption 2018-2019 (kWh/year)	Number of residents per C.S.	Thermal energy consumption PROCAPITE 2020-2021 (kWh/year/inhabitant)	Thermal energy consumption PERCAPITE 2019-2020 (kWh/year/inhabitant)
932400	964200	290	to evaluate	to evaluate
935700	933100	772	to evaluate	to evaluate
935700	933100			
648600	644600	222	7031	6327
786400	760000			
1180500	1142400	208	11133	9792
986700	894300			
1146600	1095000	211	11727	10472
1162500	1114500			
652400	656600	228	6982	6287
799600	776800			
1090500	1060500	222	10768	9840
1130550	1123890			
1391600	1474400	213	da valutare	da valutare
752800	754200	708	6955	6166
747800	714000			
826600	786600			
618000	613800			
653600	707600			
766800	697000			
659100	663900	558	to evaluate	to evaluate
1038400	1105200			
899200	1176000			
1051200	1056000			
767094	775266	882	to evaluate	to evaluate
767094	775266			
767094	775266			
767094	775266			
511396	516844			
767094	775266			
767094	775266			
767094	775266			
1581099	1581099	404	to evaluate	to evaluate
1581099	1581099			
2108132	2108132			

source: own elaboration

Thermal energy consumption PROCAPITE 2018-2019 (kWh/year/inhabitant)
to evaluate
to evaluate
6327
9792
10472
6287
9840
da valutare
6036
to evaluate
to evaluate
to evaluate

source: own elaboration

PROTOTYPE OF THE DASHBOARD:
Visualization of the web-platform



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 01: Accessibility t…

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIE

TARGET 11.1 By 2030, ensure access for all to adequa

L.

01_ACCESSIBILITY TO BASIC SERVICES by M.U.

INDICATOR 02: Availability an…

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES Makinq

TARGET 11.7 By 2030, provide universal access to safe, inclusive and

LEG…

INDICATOR_02_AAGA

IND02_ACCESSIBILITY TO PUBLIC GREE…

INDICATOR 04: Energy consu…

GOAL 7: CLEAN AND ACCESSIBLE ENERGY Ensure access

TARGET 7.1 By 2030, ensure universal access to affordab

LEG…

METABOLIC UNITS

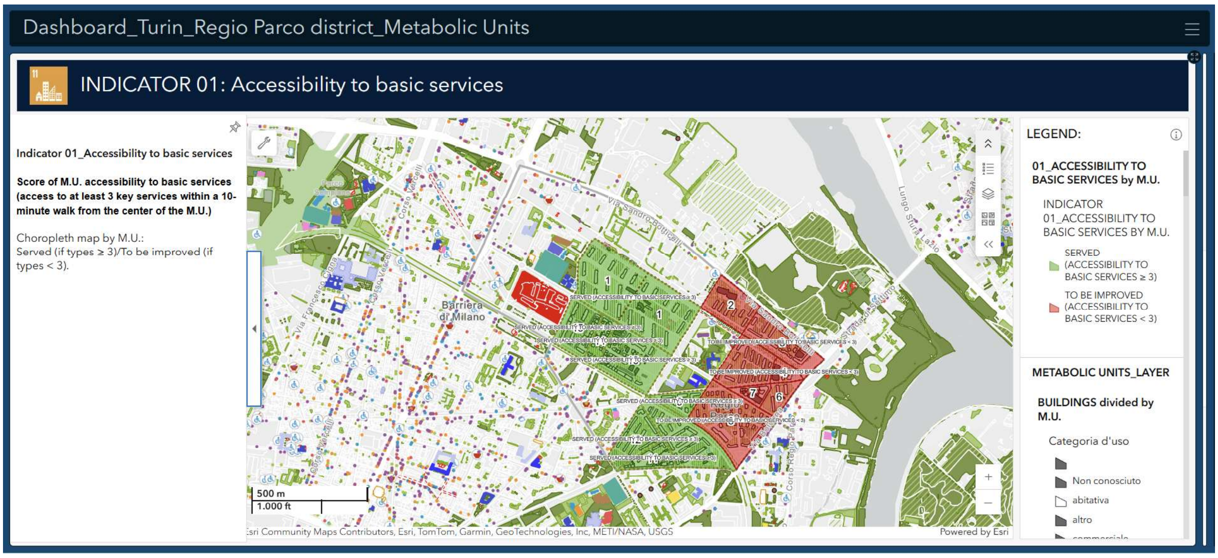
AREA PROGETTO

INDICATOR 04_CALCU

source: own elaboration;

data avaiable online at: https://www.arcgis.com/apps/dashboards/79ace57b53b54c4fbdc5ecb3d87e0a3d

PROTOTYPE OF THE DASHBOARD:
Visualization of the web-platform - INDICATOR 01



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 01: Accessibility to basic services

Indicator 01_Accessibility to basic services

Score of M.U. accessibility to basic services (access to at least 3 key services within a 10-minute walk from the center of the M.U.)

Choropleth map by M.U.:
Served (if types ≥ 3)/To be improved (if types < 3).

LEGEND:

01_ACCESSIBILITY TO BASIC SERVICES by M.U.

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES BY M.U.

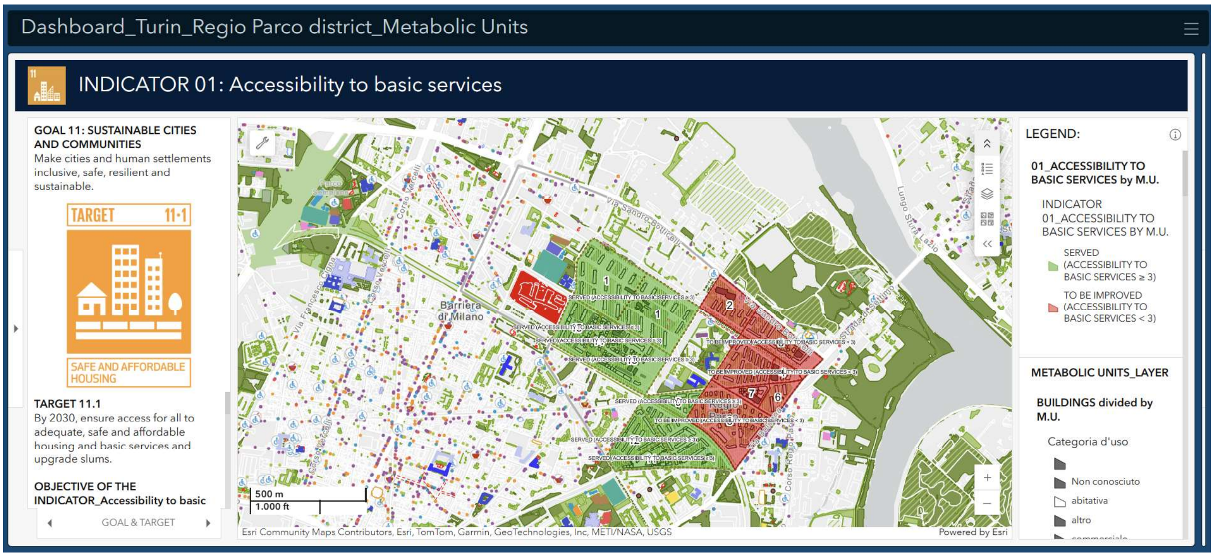
- 🟩 SERVED (ACCESSIBILITY TO BASIC SERVICES ≥ 3)
- 🟥 TO BE IMPROVED (ACCESSIBILITY TO BASIC SERVICES < 3)

METABOLIC UNITS_LAYER

BUILDINGS divided by M.U.

Categoria d'uso

- ◼
- ◼ Non conosciuto
- ◻ abitativa
- ◼ altro



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 01: Accessibility to basic services

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES
Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11·1

SAFE AND AFFORDABLE HOUSING

TARGET 11.1
By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

OBJECTIVE OF THE INDICATOR_Accessibility to basic

GOAL & TARGET

LEGEND:

01_ACCESSIBILITY TO BASIC SERVICES by M.U.

INDICATOR 01_ACCESSIBILITY TO BASIC SERVICES BY M.U.

- 🟩 SERVED (ACCESSIBILITY TO BASIC SERVICES ≥ 3)
- 🟥 TO BE IMPROVED (ACCESSIBILITY TO BASIC SERVICES < 3)

METABOLIC UNITS_LAYER

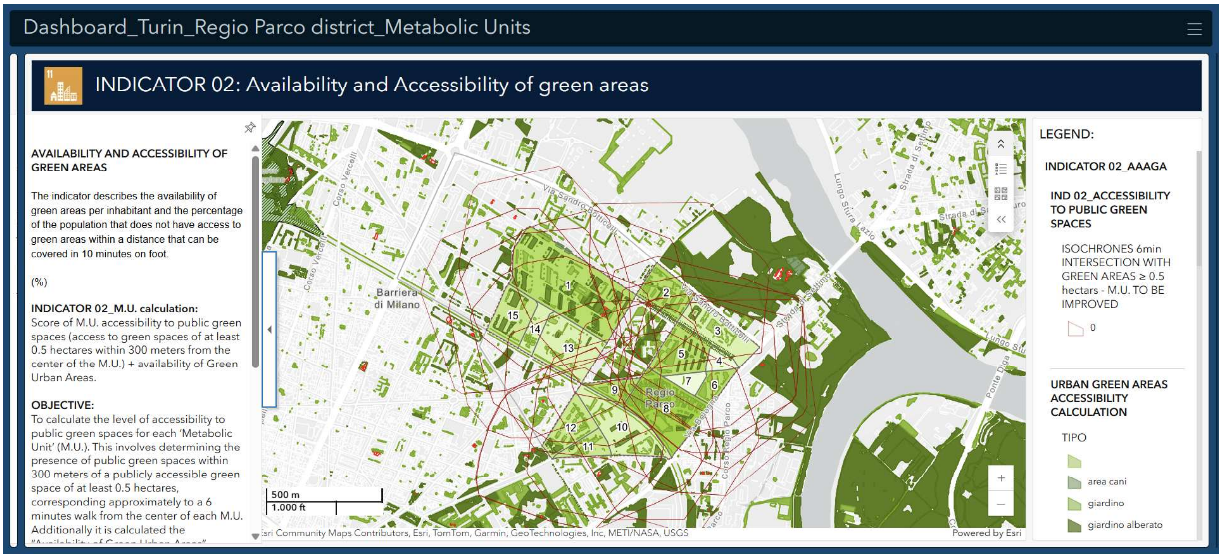
BUILDINGS divided by M.U.

Categoria d'uso

- ◼
- ◼ Non conosciuto
- ◻ abitativa
- ◼ altro

source: own elaboration;
data avaiable online at: https://www.arcgis.com/apps/dashboards/79ace57b53b54c4fbdc5ecb3d87e0a3d

PROTOTYPE OF THE DASHBOARD:
Visualization of the web-platform - INDICATOR 02



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 02: Availability and Accessibility of green areas

AVAILABILITY AND ACCESSIBILITY OF GREEN AREAS

The indicator describes the availability of green areas per inhabitant and the percentage of the population that does not have access to green areas within a distance that can be covered in 10 minutes on foot.

(%)

INDICATOR 02_M.U. calculation:
Score of M.U. accessibility to public green spaces (access to green spaces of at least 0.5 hectares within 300 meters from the center of the M.U.) + availability of Green Urban Areas.

OBJECTIVE:
To calculate the level of accessibility to public green spaces for each 'Metabolic Unit' (M.U.). This involves determining the presence of public green spaces within 300 meters of a publicly accessible green space of at least 0.5 hectares, corresponding approximately to a 6 minutes walk from the center of each M.U. Additionally it is calculated the

LEGEND:

INDICATOR 02_AAAGA

IND 02_ACCESSIBILITY TO PUBLIC GREEN SPACES

ISOCHRONES 6min INTERSECTION WITH GREEN AREAS ≥ 0.5 hectars - M.U. TO BE IMPROVED

▱ 0

URBAN GREEN AREAS ACCESSIBILITY CALCULATION

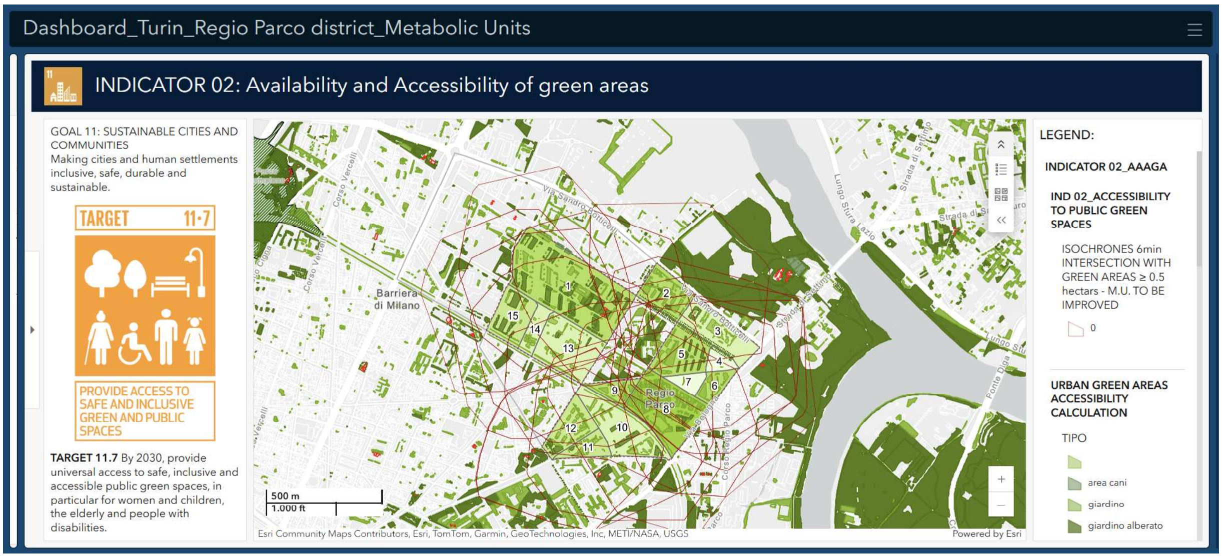
TIPO

🟩

🟩 area cani

🟩 giardino

🟩 giardino alberato



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 02: Availability and Accessibility of green areas

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES
Making cities and human settlements inclusive, safe, durable and sustainable.

TARGET 11·7

PROVIDE ACCESS TO SAFE AND INCLUSIVE GREEN AND PUBLIC SPACES

TARGET 11.7 By 2030, provide universal access to safe, inclusive and accessible public green spaces, in particular for women and children, the elderly and people with disabilities.

LEGEND:

INDICATOR 02_AAAGA

IND 02_ACCESSIBILITY TO PUBLIC GREEN SPACES

ISOCHRONES 6min INTERSECTION WITH GREEN AREAS ≥ 0.5 hectars - M.U. TO BE IMPROVED

▱ 0

URBAN GREEN AREAS ACCESSIBILITY CALCULATION

TIPO

🟩

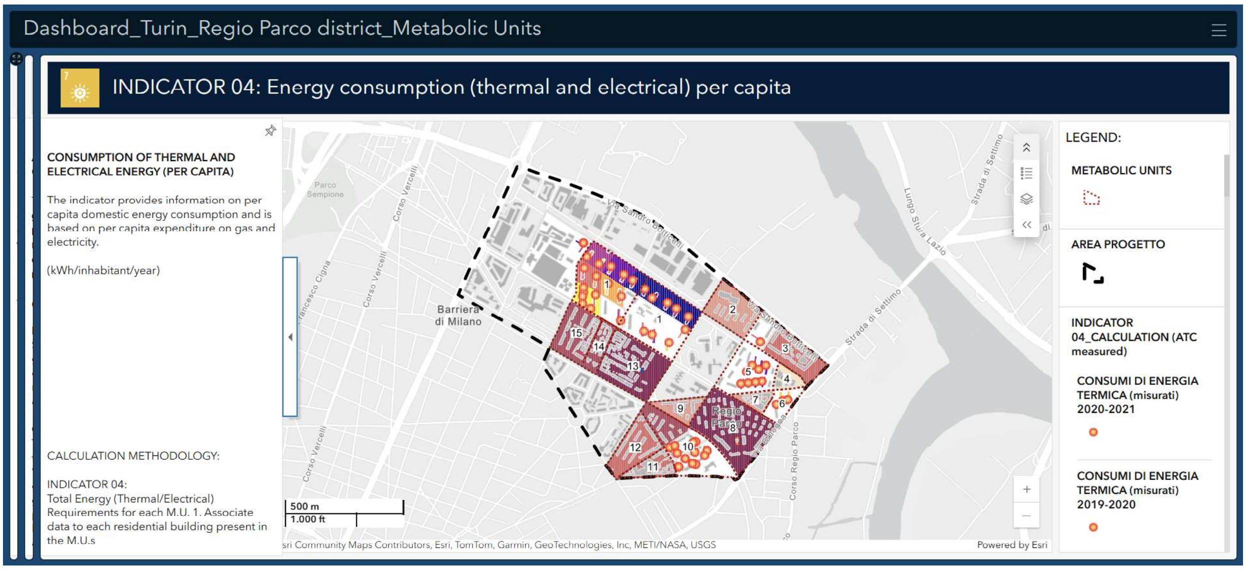
🟩 area cani

🟩 giardino

🟩 giardino alberato

source: own elaboration;
data avaiable online at: https://www.arcgis.com/apps/dashboards/79ace57b53b54c4fbdc5ecb3d87e0a3d

PROTOTYPE OF THE DASHBOARD:
Visualization of the web-platform - INDICATOR 04



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 04: Energy consumption (thermal and electrical) per capita

CONSUMPTION OF THERMAL AND ELECTRICAL ENERGY (PER CAPITA)

The indicator provides information on per capita domestic energy consumption and is based on per capita expenditure on gas and electricity.

(kWh/inhabitant/year)

CALCULATION METHODOLOGY:

INDICATOR 04:
Total Energy (Thermal/Electrical) Requirements for each M.U. 1. Associate data to each residential building present in the M.U.s

LEGEND:

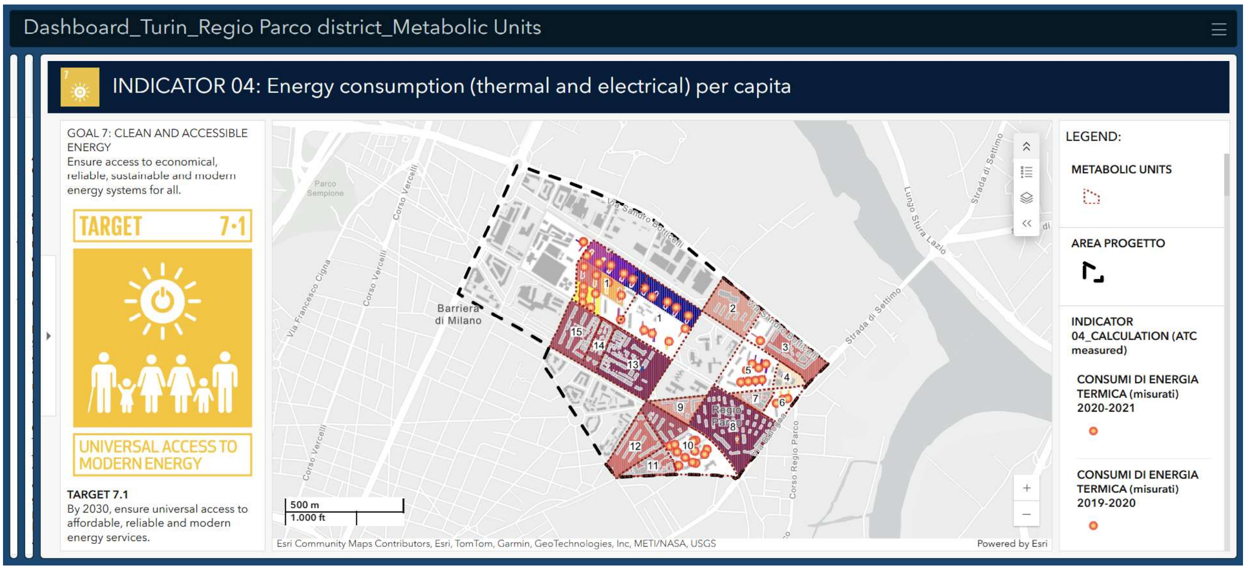
METABOLIC UNITS

AREA PROGETTO

INDICATOR 04_CALCULATION (ATC measured)

CONSUMI DI ENERGIA TERMICA (misurati) 2020-2021 ●

CONSUMI DI ENERGIA TERMICA (misurati) 2019-2020 ●



Dashboard_Turin_Regio Parco district_Metabolic Units

INDICATOR 04: Energy consumption (thermal and electrical) per capita

GOAL 7: CLEAN AND ACCESSIBLE ENERGY
Ensure access to economical, reliable, sustainable and modern energy systems for all.

TARGET 7.1
By 2030, ensure universal access to affordable, reliable and modern energy services.

LEGEND:

METABOLIC UNITS

AREA PROGETTO

INDICATOR 04_CALCULATION (ATC measured)

CONSUMI DI ENERGIA TERMICA (misurati) 2020-2021 ●

CONSUMI DI ENERGIA TERMICA (misurati) 2019-2020 ●

source: own elaboration;
data avaiable online at: https://www.arcgis.com/apps/dashboards/79ace57b53b54c4fbdc5ecb3d87e0a3d

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a.a. 2024/2025

Chiara Bitonto Carlucci