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# SMART CITIES AND SUSTAINABLE REGIONAL DEVELOPMENT

Szczecin
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# CONTENTS

## LIST OF FIGURES AND TABLES

# INTRODUCTION

Local governments face unprecedented endogenous and exogenous challenges resulting from dynamic social, technological, environmental, and economic changes. The transformation of traditional models of governance, planning, and public service delivery is a natural response and a necessity. In an environment of growing urbanization, digitization, various crises, and changing demographics, it is becoming apparent that existing approaches to local government management are insufficient. Archaic, hierarchical, and isolated approaches to territorial management are becoming less and less effective in an environment that requires flexibility, adaptability, and systemic thinking.

In response to these challenges, the concept of Smart City has been established in recent years. It is a holistic and dynamic framework for the strategic direction of urban and regional development. By integrating modern technologies, participatory processes, environmental principles, and social inclusion into the daily functioning of local governments, the conditions are created for the emergence of cities that are able to respond effectively to the changing needs of the population, optimize the use of available resources, and at the same time ensure sustainable and inclusive development.

The aim of this scientific monograph is to provide a comprehensive view of the Smart City phenomenon and to contribute to the promotion of the ideas and principles of this concept. The scientific monograph is based on qualitative and quantitative methods of scientific research and, through empirical data and examples of good practice, identifies the main benefits, challenges, and limitations of applying smart solutions in a territorial-administrative context.

In the first chapter of the scientific monograph, the authors focus on the theoretical foundations, stages of development, and selected frameworks of the Smart City concept. In addition, they pay attention to understanding the importance of smart development.

Following on from this, the authors focus on the individual components of Smart City, which they identify as key areas of smart urban development.

The chapter on Smart Governance focuses on the issue of effective and inclusive city management. The authors focus on identifying opportunities for the use of data, open platforms, participatory tools, and digital services.

In the third chapter, the authors develop the topic of Smart Economy. They emphasize the importance of innovation and digital technologies, which are essential for the growth and development of the business environment and social inclusion.

The fourth chapter focuses on Smart Living and smart solutions for modern life. The focus is on quality of life, health, safety, accessibility of services, inclusion, and cultural development.

The fifth chapter, Smart Mobility and Transport, elaborates on the concept of smart mobility. The chapter reflects the need to transition from traditional transport models to integrated, flexible, and environmentally responsible solutions.

The sixth chapter deals with Smart Waste Management, analyzing the challenges associated with growing municipal waste production and the deteriorating state of the environment. The authors focus on the possibilities of using smart technologies in waste management.

In the seventh chapter, Smart Energy, the authors point out the strategic importance of cities' transition to sustainable and smart energy models. They pay particular attention to the use of renewable energy sources, increasing

energy efficiency, implementing smart grid technologies, and promoting the energy self-sufficiency of cities.

The eighth chapter presents the results of a questionnaire survey focused on the implementation of SMART solutions in local governments in the Slovak Republic. The survey, conducted between January and September 2025, monitored the priorities, activities, barriers, sources of financing, and perceived benefits of the SMART concept in the context of the 2030 Agenda for Sustainable Development goals. One hundred municipalities participated in the survey, with a response rate of 60%.

The scientific monograph as a whole offers a comprehensive view of the Smart City concept from multiple perspectives. It uses an interdisciplinary approach, linking knowledge from the fields of public administration, urbanism, technology, economics, sociology, and environmental sciences.

The authors believe that this publication will contribute to the development of professional discourse on the future of cities in the digital era and will inspire public policy makers, experts, local governments, and civil society.

The scientific monograph is the result of VEGA [Reg. No.: 1/0396/23]: "*Smart Solutions and their impact on social and economic regional development in terms of Agenda 2030*".

Authors

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# CHAPTER 1. SMART CITY BASICS

The issue of Smart Cities is extremely topical and important given the need to redefine the paradigm of how cities function. Smart City is neither an ad hoc trend, nor an isolated technological fad, nor a final state. It is a complex, dynamic evolutionary framework that systematically integrates innovative approaches, digital technologies and participatory processes into the everyday functioning of urban structures.

The Smart City concept is as per holistic, sophisticated solutions. These solutions transform the understanding and dimension of public administration. Thanks to this concept, urban services are managed more efficiently, decision-making processes are optimised, services are more accessible, and responses to residents' needs are more flexible. Cities are thus transformed not only into technologically advanced units. They become inclusive and adaptable units. Smart Cities are truly prepared to proactively face future social and environmental challenges. The uniqueness of the Smart City ecosystem also lies in the integration of environmental principles, economic rationality and social inclusion. This is what significantly distinguishes Smart Cities from traditional forms of territorial-administrative units.

## 1.1 Smart City - the essence of the phenomenon

Smart City is a phenomenon that transcends the ordinary nature of a city and life in it. It is a new way of thinking about the city, changing the very essence of its role. It reflects the desire of actors for change and uniqueness. It represents a modern approach to management through innovative

technologies and data-oriented solutions that are not only effective but also humane.

Smart City is the answer to the questions of the future, the challenges of the present (climatic, social and technological) and the ecosystem of the present, which responds sensitively to the needs of its inhabitants. However, the absence of an absolute definition and the diversity of interpretations of the term Smart City cause confusion in its implementation, evaluation and even in understanding its essence. It is a concept that straddles the boundary between technological progress and human experience, between data and emotions, between infrastructure and community.

The term Smart City resonates in professional circles, political visions and public debates. However, it is not always used with sufficient precision and contextual understanding (Ismagilova et al., 2019). In many cases, it is reduced to a buzzword whose meaning is narrowed down to technological innovation (Murgante & Borruso, 2015). It is often transformed into an ideological construct. It legitimises technological interventions regardless of their actual benefit to the community. The archaic perception of the Smart City concept, i.e. technological discourse and the absence of a comprehensive framework for evaluating urban initiatives, can be considered conceptually rigid. Therefore, the current paradigmatic framework replaces the technologically determined approach and promotes an interdisciplinary approach. This means that not only technologies but also social innovations, participatory planning, environmental sustainability and ethical impact assessment are coming to the fore. Such an approach allows us to perceive the city as a complex ecosystem where technological solutions serve as means, not as ends.

Terminological ambiguity and conceptual dispersion of the term Smart City is one of the key problems of its current use. Due to the absence of a unified framework, this term loses its analytical precision.

Different stakeholder groups, from technology companies to city governments to academia, interpret it differently, leading to fragmented approaches and unclear goals. Interpretative coherence is also undermined by the fact that the term Smart City is often incorrectly equated with the concepts of digital city, green city or sustainable city.

Recognising its multidimensionality and dynamism is important for a holistic understanding of the meaning of Smart City. It is these two fundamental characteristics that define it and distinguish it from traditional approaches to the city. While multidimensionality refers to the technological, environmental, social and economic aspects that intertwine and shape the structure of urban life, dynamics refers to the concept's ability to respond flexibly to changing conditions, challenges and needs of society.

The term Smart City can therefore be interpreted as an active tool for modern urban environment management. In this context, it is a well-thought-out framework of a strategic and systemic nature that enables cities, municipalities and regions to respond to current challenges while planning for sustainable development. At the same time, it opens up space for a deeper understanding of the role of local government in the process of their transformation into smart entities, which are the basis of the concept itself and its practical application.

The Smart City concept in the context of strategic management of territorial administrative units (cities, municipalities, regions) represents an integrated model of urban environment development, management and planning. The interconnection of technological innovations with public policy, planning and territorial management creates a framework that takes

into account the specific needs of particular local communities and enables their active involvement in decision-making processes. The primary goal of Smart City is to ensure, improve and enhance the quality of life of residents (McLean, 2021, Gracias et al., 2023) through the use of modern information and communication technologies.

Modern information and communication technologies serve as a functional means of streamlining decisionmaking processes, improving the accessibility of public services, and promoting transparency and participation in services (Kumar et al., 2020, White, 2024). Their implementation enables local governments to respond flexibly to changing conditions and the needs of the population, thereby increasing the overall adaptability and resilience of territorial administrative units. The application of modern information and communication technologies leads to more interactive and responsive management of territorial administrative units and the satisfaction of client needs (citizens, entrepreneurs), as well as more effective achievement of the economic, social and environmental goals of the city (Dameri, 2013).

These facts show that Smart City is not just about hard modern technologies. Smart City is about how hard infrastructure is reflected in everyday life, decision-making and coexistence in urban space. Smart City is therefore about building an integrated and sustainable urban environment that makes real use of modern technologies to improve the quality of life of residents, use resources efficiently and increase participation (MIRRI SR, 2019, MIRRI SR, 2022a). It is precisely the participation and lively synergy of actors in territorial administrative units that motivates the Smart City concept. Thanks to dynamic synergy and cooperation between actors, local governments form a unique ecosystem of the 21st century. By understanding and shifting the Smart City concept to this level

(Czupich, 2019, Stawasz, 2015), resources are used more efficiently, and public services are of higher quality. The coexistence of *"hard*" (technological) and "*soft*" (socio-cultural) aspects of city management and the harmony of "*grey*" (technical) and "*green*" (natural) infrastructure of territorial administrative units is a basic prerequisite for achieving functional, environmentally sustainable and socially inclusive local government.

Given rapid technological progress and constantly changing social, environmental and economic conditions, the Smart City concept is also an open framework. There is no local government that has fulfilled the Smart City dimension to such an extent that it has nothing left to complete. One of the main challenges in this context is the exponential dimension of the development of artificial intelligence systems, platforms and elements. Local governments are neither systemically nor capacitatively equipped for the dynamics of the current technological environment. The enormous efforts of local governments to be flexible and adaptable often reach their limits. Limits such as institutional capacity, technological maturity and human resources are barriers that prevent local governments from fully exploiting the potential of smart solutions and innovations within the Smart City concept. As a result, there is a disproportion between the speed of technological development and the ability of local governments to respond effectively to new challenges. On the other hand, it is generally accepted that local authorities strive to do everything possible to make residents and the community feel comfortable. They actively declare their ambition to become fully-fledged Smart Cities and to implement innovative solutions that emphasise quality of life, inclusion and sustainability. For this reason, systematic support, strategic partnerships and investments in digital infrastructure and human capital are essential, both on the part of local governments and the state. (Pauhofová et al., 2019).

The need to address this situation, as well as the need to discover, experiment and implement 21st century (information and communication) technologies in order to contribute to improving the quality of life in one's own community and to promote social inclusion, is openly discussed by Colding et al. (2024), Veloso et al. (2022), Onoja & Ajala (2023), Müller-Eie & Kosmidis (2023), Lehr (City Innovators Forum, 2018).

Dialogue and mutual understanding of the needs of stakeholders are key prerequisites for the success of a Smart City. However, for technologies to be truly effective and beneficial, their implementation must be as per an understanding of the needs of the local community. Therefore, technological and social innovation must go hand in hand. Only in this way can we ensure that technological solutions are not only innovative, but also inclusive, sustainable and truly beneficial to the community. The introduction of smart solutions should not be merely a response to current trends, but the result of strategic and responsible decision-making that takes into account the local context, the needs of residents and a long-term vision for development.

As Garlík (2020, p. 254) states, "*the effort to achieve Smart City status is turning into ever-increasing pressure. Therefore, it is necessary to implement consistency, technical sophistication and, above all, methods of cybernetics and artificial intelligence, which, in the context of the integration of communication and computing systems, ensure the required efficiency and sustainability of Smart Cities.*"

According to Kozłowski & Suwar (2021), a Smart City represents a holistic approach to urban development as per the synergy of numerous determinants. Among the determinants of the basic interface, Lombardi et al. (2012) include modern information and communication technologies integrating the economy, people, life, the environment,

management, and mobility. However, since no two cities have the same framework, statistics, history or infrastructure, a blind approach to Smart City cannot be applied to most cities (White, 2024).

A Smart City is therefore a city that holistically manages and integrally implements its long-term qualitative and numerically expressed development strategy, cultivating the political, social and spatial environment of the city with the aim of increasing its quality and attractiveness and limiting negative impacts on the environment (MMR, 2015).

Identifying the needs and expectations of residents in administrative units requires the thorough involvement of all relevant actors in individual processes. Since a Smart City should primarily reflect the specific needs of the residents of a given territorial administrative unit and respond to these needs appropriately (Jelínek et al. 2020), open dialogue and facilitated meetings are key determinants of the quality of the proposed solutions and their social acceptability. It is impossible to understand the context, gain trust, accept change and support ideas without a participatory approach. In this spirit, the areas of smart transport, energy efficiency, sustainable waste management, strengthening security mechanisms and modernising public administration have recently come to the fore in the interests of the actors involved (European Commission, 2020).

Thanks to the enormous influence of the external environment, as well as the ability to reflect on current needs and anticipate future challenges, Smart City is becoming an active catalyst for social, technological and environmental transformation of the environment, structures, infrastructure systems and communities (José & Rodrigues, 2024, Angelidou, 2015).

In response to the dynamic development of technological innovations, growing environmental challenges and the need for effective urban management, the concept of a "*Smart City*" is naturally constantly being

redefined. Proof of this is the Smart Cities & Communities Industrial Initiative (2011). This initiative is the EU's first coordinated step towards the systematic development of Smart Cities. Its main objective was to reduce the environmental impact of the transport and energy sectors through the introduction of innovative technologies and sustainable solutions. The EU followed up on this initiative by launching the European Innovation Partnership for Smart Cities and Communities (EIP-SCC) in 2012, which defined the basic structure of the Smart City concept. The cooperation platform emphasises the integration of information and communication technologies (ICT) as a key tool for increasing the efficiency of urban services, improving the quality of life of residents and promoting sustainable development. In addition, it promotes cooperation between cities, technology companies, research institutions and civil society, giving the platform a new dimension. It is becoming a tool for the exchange of best practices, pilot projects and scalable solutions in the field of smart urban development.

The current stage of the Smart City paradigm focuses on the more efficient use of physical infrastructure (e.g. roads, built environment, etc.) through artificial intelligence and data analysis, with the aim of promoting a strong, healthy and inclusive economic, social and cultural life (Garlík, 2020). In the context of the current paradigm, artificial intelligence is a transformative element that enables city management to be proactive. Thanks to its ability to synthesise data and data sources in real time, which come from a wide range of different sources and are used for a variety of purposes (Pavlík et al., 2020), AI redefines the way cities can identify needs, allocate resources, and propose interventions in their own structural and functional identity.

The categorisation of basic areas of urban development in the context of Smart Cities is as per a structured framework of six pillars that reflect the key

needs for the transformation of local governments (Lombardi et al., 2012, Albino et al., 2015, Patel & Bhagat, 2019, Moura & de Abreu e Silva, 2021, MIRRI SR, 2022a):

***Smart People*** - human capital as the basis for an innovative and inclusive region, the qualifications and education of city residents, as well as social interactions related to integration and public life and openness to the world are prerequisites for increasing the adaptive capacity of the city, its innovative potential and ability to respond to complex social challenges:

- digital inclusion and education,
- developing and retaining talent in the region,
- crowdsourcing of ideas through digital tools for public policy-making.

***Smart Governance*** - governance through digital technologies as the basis for effective, efficient, transparent and participatory management of the city, urban policies and public decision-making processes:

- transparency and digitisation of public administration,
- citizen participation in local government management,
- digital platforms, process automation and predictive modelling of public needs.

***Smart Economy*** - economic transformation as the basis for the sustainability and competitiveness of local government, the development of e-business and e-commerce, and the improvement of opportunities related to the production and provision of services and innovations, as well as new products, services or business models:

- support for innovation ecosystems and start-ups,
- green and circular economy,
- local production chains and services.

***Smart Infrastructure/Mobility*** – adaptive elements of the spatial framework as the basis for a safe public space:

- addressing undesirable situations and safety, including space monitoring,
- barrier-free solutions and inclusive design of public spaces,
- electromobility (including public transport) and support for shared mobility.

***Smart Environment*** - the environment as the basis for ecological stability and climate resilience of local government, with an emphasis on building and maintaining natural living conditions in the city:

- promotion of the use of renewable energy sources,
- protection of biodiversity and green spaces,
- sorting and recycling.

***Smart Living*** - quality of life as the basis for social inclusion, health and cultural development, with particular attention paid to safety, living conditions of residents and the stimulation of tourism:

- energy-efficient buildings and green neighbourhoods,
- smart homes,
- creative centres and services.

Each of these pillars represents a separate but interconnected system in which artificial intelligence, automation and digital connectivity play a key role. This role consists in shaping adaptive, inclusive and sustainable ecosystems.

All three substrates are important for achieving development, stability and harmonious functioning of territorial administrative units. Their synergistic and holistic effect ensures the effective fulfilment of local government tasks, but if even one of the substrates does not function optimally, it is likely that

the functionality of the remaining substrates will also be disrupted (over time).

The disruption of the healthy functioning of local government can result in the socio-economic stagnation of the territorial-administrative unit, population outflow, loss of investment, a slowdown in the comprehensive development and standard of living of its inhabitants, a reduction in the guarantee of the quantitative and qualitative aspects of public services, a weakening of infrastructure, a decline or loss of confidence in the ability of local government to deal with threats, disruption and weakening of social cohesion, destabilisation of local communities, etc.

These negative consequences can be prevented through systematic monitoring, regular evaluation of individual substrates and effective support for mutual cooperation on the part of the state.

The pillars of Smart City represent thematically defined areas reflecting the strategic dimensions of local government development. However, their significance cannot be reduced to this framework categorisation alone. The pillars of Smart City are so-called conceptual starting points. These must be translated into specific organisational structures, mechanisms, infrastructure solutions and other outputs. It is at this point that the levels and components of Smart City become important (Ministry of Regional Development of the Czech Republic, 2018):

***Organisation*** – emphasis on the organisation and management system of the territorial administrative unit:

- *Political Commitment* - Smart City vision (formalised document/framework) - qualitative (descriptive) and quantitative (numerical) objectives that define the strategic direction of the city,
- *Organisation and Responsibility* – designation of a department and assignment of personal responsibility within the implementation of

Smart City, which is in close contact with the city's political leadership.

- *Strategy/Action Plan* - developing a strategic/action plan that takes into account the city's plans and intentions in terms of land development objectives.
- *Cooperation and Partnership* - creation of a working group composed of several interested parties and organisations (e.g. companies, universities, banks, users, associations and others).

***Community*** – emphasis on supporting community life, citizens perceived as part of the community participating in the creation and decision-making on public affairs and the development of the local environment:

- *Activation and Support of Individuals in the Community* - collection of ideas, observations and comments for improving the quality of life through applications or a community coordinator, with the aim of understanding and eliminating barriers.
- *Creating Space for Communities and Self-development* - various motivational and support programmes for citizens.
- *Sharing/Community Economy* - sharing concepts (transport, employment, education, etc.) that enable the effective and sustainable use of resources wherever it makes sense, or that promote social inclusion, community cooperation and the reduction of environmental burdens.
- *Cultivation of Public Space* - a comprehensible spatial plan, including its visualisation, which reflects the need for diversity of functions, roles of public space and at the same time supports an inclusive, and functionally connected urban environment.

***Infrastructure*** – emphasis on synergy between implemented technologies and approach to infrastructure development, grey infrastructure

(roads, buildings, networks, etc.) is embedded in green infrastructure (public greenery, environment):

- *Comprehensive Coverage* - implementation and development from top to bottom through technology and comprehensive regulations, data collection, management and use of scenarios.
- *Multi-purpose Solution* - covering several needs at once, i.e. one investment, platforms or technology for multiple purposes.
- *Integrated Solution* - interconnection and integrated management or central administration (e.g. data centre, platform, etc.).
- *Open Solution* - data available to citizens, organisations, companies, i.e. open data.

***The resulting quality of life and attractiveness of the city*** – emphasis on the results and objectives of the Smart City concept:

- *a connected, open and cooperative city* - diversity of services, space for business,
- *a healthy, clean, cultivated and pleasant city to live in* - environmental impact on citizens (e.g. minimisation of emissions, noise vs. sufficient public green spaces, cultivation of the environment),
- *an economically interesting, attractive and healthy city* - positive financial impact on citizens, economic growth of the city (driving force),
- *a city with a high reputation/renown* - media image of the city.

All these levels and components of Smart City represent the practical level of implementation of the transformation of cities to a new level and dimension. They are a concrete expression of how the Smart City vision is being translated into real steps, processes and measurable results. The success of the entire transformation process requires their coordinated interaction.

Only in this way is it possible to create a functional framework for strategic planning, participatory decision-making, technological integration and improving the quality of life.

As per the above, we define the term "Smart City" as a modern, dynamic urban ecosystem of an innovative and inclusive nature, achieving economic, social and political efficiency through technology, data and participatory management.

Table 1.1

Smart City - common elements in definitions

| | |
|---|---|
| **Information and communication technologies** | • Use of ICT, IoT, AI, big data for managing urban processes<br>• Automation, sensors, digital services |
| **Sustainability** | • Reducing environmental impact<br>• Efficient use of resources (energy, water, transport) |
| **Quality of Life** | • Ssafety, health, education, culture, social<br>• Improved accessibility of services |
| **Participation and governance** | • Transparent governance<br>• Citizen involvement in decision-making |

Source: own elaboration as per Yigitcanlar et al., 2019, Hajek et al. 2022

Regardless of context, most definitions of Smart City share common features such as ICT, sustainability, quality of life and participation (see Table 1.1).

As per the above, we define the term "Smart City" as a modern, dynamic urban ecosystem of an innovative and inclusive nature that achieves economic, social and political efficiency through technology, data and participatory governance.

## 1.2 Development of the Smart City concept

The origins of the Smart City concept are closely linked to technological progress and the use of ICT in the urban environment (see Table 1.2).

Table 1.2

Smart City - stages of concept development

**Smart City 1.0** (do 2010)

- technocratic centralized approach
- technology, infrastructure, process automation
- entry of technology giants: IBM, Cisco, Microsoft, Siemens, etc.
- citizens as passive actors

**Smart City 2.0** (2010-2020)

- open, adaptive approach
- participation (platform for cooperation between technology, local government, and citizens) and sustainability
- citizens as active participants

**Smart City 3.0** (2020-súčasnosť)

- a value-oriented approach that promotes social justice, environmental sustainability, and digital sovereignty
- law, security, ethics, and inclusion
- citizens as co-authors

Source: own processing as per Ali et al., 2023, Hajek et al. 2022, Soe et al., 2021, Garlík, 2020, Yigitcanlar et al., 2019

Technological corporations (e.g. IBM, Microsoft, etc.) play a key role in this transformation process, ***Smart City 1.0 – Technological Determinism (***until approx. 2010). Corporations are beginning to perceive urban spaces as laboratories for innovative experiments. As a result, cities are becoming testing grounds for new digital solutions. The boom in the implementation of solutions as per sensor networks, smart lighting and monitoring systems is leading to the formation of so-called smart infrastructures that enable cities to respond to challenges in real time.

The experiments include sensor networks monitoring air quality and energy consumption, as well as algorithmic traffic management enabling efficient real-time traffic planning. These technologies are not just an addition to the existing infrastructure but are gradually shaping a new understanding of the city as a dynamic platform for technological innovation.

Digital tools and communication infrastructure are the basis for more efficient process management, service provision and sustainable use of resources in the Smart City 1.0 phase (Hajek et al., 2022). With cities being perceived as objects of technological optimisation, citizens play a predominantly passive role.

With the rise of information technology, there has been a shift from traditional, instinctive decision-making to a data-driven model of ***Smart City 2.0*** governance **–** ***Participatory and open governance*** (2010-2020). The concept of open government, transparency and public participation, where digital tools serve as a means of strengthening democratic processes. The city has become a platform for cooperation between local government, civil society and technology players. The use of open data portals, participatory budgeting and the development of green technologies are becoming essential. The use of big data to optimise city services, predict

residents' needs and increase the efficiency of the public sector is a key pillar of the digital transformation of the urban environment. This transition has enabled the emergence of new forms of urban management. The adaptability and responsiveness of urban systems is as per algorithms and analytical tools. These tools support real-time decision-making, placing cities in the role of intelligently managed entities capable of responding flexibly to changing conditions and the needs of the population. Citizens are taking an active role in co-creating urban policies (Anagnostopoulos, 2021, Nijkamp et al. 2022). New forms of digital citizenship are emerging, redefining the relationship between residents and the city.

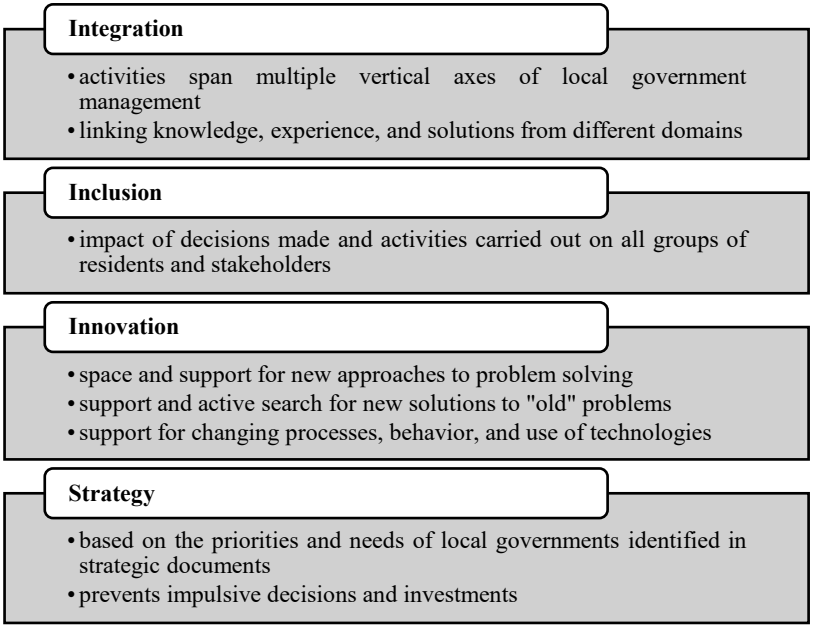
However, the direction of the Smart City concept is shaped not only by technological developments, but also by global environmental challenges. The current phase, ***Smart City 3.0 – Value-Oriented and Ethical Approach (***2020-present), reflects the need to integrate ethical principles, digital rights, climate resilience and social justice into the concept of a Smart City . Climate change and international commitments, such as the Paris Agreement, oblige city authorities to actively respond to the need for ecological transformation. In this context, Smart City 3.0 is redefined as a resilient and environmentally responsible environment in which technologies are used to support adaptation to climate risks, reduce carbon footprints and manage energy, water and mobility efficiently (Gramchuk et al., 2024). The city is understood as a living ecosystem that supports inclusive decision-making, environmental sustainability (Kirimtat et al., 2020) and digital sovereignty. Emphasis is placed on privacy protection, equal access to digital services and real-time adaptability to residents' needs.

Smart City thus becomes a value-oriented concept (Szarek-Iwaniuk & Senetra, 2020) in which technology is not the goal but a means to achieve inclusive, equitable and sustainable urban living (See Table 1.3). There is a

need for new competencies in the areas of digital ethics, urban philosophy and social inclusion.

Table 1.3

Smart City - principles of development




Source: MIRRI SR, 2022a

The exponential development of ICT, advanced analytical tools for processing big data, the spread of the Internet of Things (IoT), and theapplication of artificial intelligence (AI) in urban management are prerequisites for cities of the future to be able to function as autonomous, predictive and adaptive systems (Alahi et al., 2023). The expansion of the use of artificial intelligence, the new generation of the Internet of Things, neural networks and biotechnological interfaces are prerequisites for the next stage

of Smart City development in the near future (See Figure 1.1). Urban systems will be able to recognise emotional and social behaviour patterns, shifting the interaction between people and cities to an empathetic level. Citizens will take on a deeper role as co-creators, with their voices integrated not only through digital platforms but also through sensitive interfaces (voice, gestures, biorhythms). The interaction between people and cities will become multi-layered.

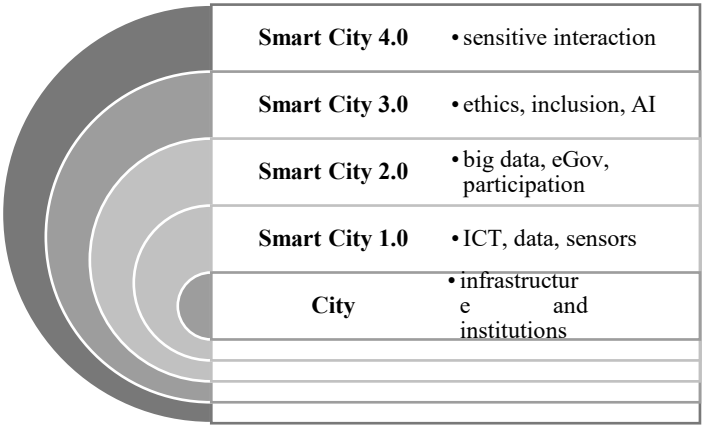



Figure 1.1 Smart City - paradigms

Source: own processing

## 1.3 Smart City in the context of Agenda 2030

Agenda 2030 for Sustainable Development is a global framework adopted by UN member states in 2015. The goal of the Agenda is to transform the world by 2030 through 17 Sustainable Development Goals (SDGs). The goals cover a wide range of areas such as poverty eradication, quality education, gender equality, climate action, sustainable cities and innovation (European Commission. 2024, Agenda 2030, Khosravani, 2025).

The normative power of the Agenda lies in its universality (See Table 1.4). This universality means that the Agenda is valid for all countries regardless of their level of development. In addition, it is as per the principles of integration, participation and inclusion, which play an important role in building a healthy environment.

As Walsh, Banerjee and Murphy (2022) point out, implementing the Agenda requires more than just technocratic planning. The Agenda requires systemic change in institutions, norms and power relations, which, in response to global goals, will reflect the requirements and possibilities of national and regional policies. This process can be described as key to the entire mechanism of the Agenda.

As research on foresight mechanisms and the future of the SDGs (UN SDGs, 2025) shows, it is essential to involve local governments, civil society and technology actors in the creation of visions and plans that reflect the specific needs of a given territory (Bonsu et al., 2020). Case studies from Utrecht University (Hickmann et al., 2021) show that local implementation frameworks, such as urban action plans, are where global vision meets everyday reality. In this sense, Smart City is a practical expression of the transformative ethos of Agenda 2030.

The issue of local government development is addressed primarily in the areas of inclusiveness, safety, resilience and sustainability of cities (SDG 11). As research by Hickmann et al. (2021) shows, the transformative potential of Agenda 2030 is most evident at the city level, where global goals meet local reality. Cities are laboratories of innovation, but they are also places where systemic barriers, lack of data, fragmentation of policies and limited capacities of local governments manifest themselves.

Table 1.4

Agenda 2030 - Sustainable Development Goals

| Goal 1. End poverty in all its forms everywhere |
|---|
| eradicate extreme poverty for all people everywhere |
| Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture |
| end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round; end all forms of malnutrition; double the agricultural productivity and incomes of small-scale food producers; increase investment in rural infrastructure |
| Goal 3. Ensure healthy lives and promote well-being for all at all ages |
| reduce the global maternal mortality ratio; reduce neonatal mortality; end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases; substantially reduce the number of deaths and injuries from road traffic accidents |
| Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all |
| ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes; eliminate gender disparities in education; substantially expand globally the number of scholarships available to developing countries |
| Goal 5. Achieve gender equality and empower all women and girls |
| end all forms of discrimination against all women and girls everywhere; eliminate all forms of violence against all women and girls; ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life |
| Goal 6. Ensure availability and sustainable management of water and sanitation for all |
| achieve access to safe and affordable drinking water for all; achieve access to adequate and equitable sanitation; improve water quality by reducing pollution; protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes |
| Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all |
| ensure universal access to affordable, reliable and modern energy services; increase substantially the share of renewable energy in the global energy mix |
| Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all |

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| sustain per capita economic growth in accordance with national circumstances; achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high value added and labour-intensive sectors; achieve full and productive employment and decent work |
| Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation |
| develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure; promote inclusive and sustainable industrialization |
| Goal 10. Reduce inequality within and among countries |
| progressively achieve and sustain income growth; ensure equal opportunity and reduce inequalities of outcome; encourage official development assistance and financial flows |
| Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable |
| provide access accessible and sustainable transport systems for all, expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons; enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in countries; reduce the adverse per capita environmental impact of cities; provide universal access to safe, inclusive and accessible, green and public spaces; support positive economic, social and environmental links between urban, peri-urban and rural areas |
| Goal 12. Ensure sustainable consumption and production patterns |
| implement a framework of programmes on sustainable consumption and production; substantially reduce waste generation, including food waste |
| Goal 13. Take urgent action to combat climate change and its impacts |
| strengthen resilience and adaptive capacity to climate-related hazards and natural disasters; integrate climate change measures into national policies, strategies and planning |
| Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development |
| prevent and significantly reduce marine pollution of all kinds; effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices |
| Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss |

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| ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services; combat desertification, restore degraded land and soil; ensure the conservation of mountain ecosystems; integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts |
| Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels |
| significantly reduce all forms of violence and related death rates everywhere; end abuse, exploitation, trafficking and all forms of violence against and torture of children; promote the rule of law at the national and international levels; substantially reduce corruption and bribery in all their forms; develop effective, accountable and transparent institutions at all level; ensure responsive, inclusive, participatory and representative decision-making at all levels |
| Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development |
| strengthen domestic resource mobilization; enhance North-South, South-South and triangular regional and international cooperation; enhance international support for implementing effective and targeted capacity-building; promote a universal, rules-based, open, non-discriminatory and equitable multilateral trading system; enhance the global partnership |

Source: UN SDGs (2025)

At the same time, however, technological innovation alone is not enough. As Weber (2023) points out, the principle of "*Leave No One* Behind" often becomes a rhetorical tool that masks real inequalities in access to decision-making. Smart City must therefore be understood not only as a technological project, but as a political tool that promotes inclusion, transparency and equality.

In the context of SDG 11: "*Make cities inclusive, safe, resilient and* sustainable", Smart City appears to be a concrete response to the challenges of urbanisation, the climate crisis and social inequality (UNECE, 2021). These challenges can be overcome through "policy integration", i.e. linking sectoral policies into a single framework, as emphasised by Bornemann and

Weiland (2021), which is the basis of the Smart City concept. In addition, Smart City represents a strategic framework that uses digital technologies, geospatial data, sensor systems and participatory management to improve the quality of life of residents, use resources efficiently and reduce environmental impact (Cogitatio Press, 2021). In this sense, Smart City is intended to serve as a practical tool for achieving set goals.

The link between Agenda 2030 and the Smart City concept (SDG11) is also evident in the following areas: intelligent transport systems contribute to reducing emissions (SDG 13), smart grid technologies support renewable energy sources (SDG 7), digital platforms increase transparency and citizen participation (SDG 16), and sensor systems optimise waste and water management (SDGs 6 and 12) (Cogitatio Press, 2021, UN SDGs, 2025).

The Slovak Republic has also committed to achieving the goals of Agenda 2030. In this context, it has created several institutional tools for its implementation. The Council of the Government of the Slovak Republic for Agenda 2030 was established, thematic working groups were set up, and in 2021, *the "Vision and Strategy for the Development of Slovakia until 2030*" (known as Slovakia 2030) was adopted. The vision defines three integrated development programmes, namely resource protection and development, sustainable resource use, and community and regional development (Gazdova et al., 2020).

## 1.4 Smart City - performance dynamics in the European context

Cities around the world are increasingly embarking on the path of smart development. This trend is a response to the growing challenges of urbanisation, climate change, traffic congestion and the need for more efficient management of public services. Cities that have opted for a "*smart*" approach are striving to integrate modern technologies into their everyday

functioning. Their motivation is to improve the quality of life of their residents, improve the accessibility of services and promote sustainability. In practice, this means introducing smart lighting, air quality sensors, digital platforms for communication with authorities, and shared mobility applications.

The most important comparative tool for evaluating city performance in this area is the IMD Smart City Index (IMD, 2025). Thanks to this index, hundreds of cities are compared annually as per their technological readiness and residents' perceptions.

The Smart City Index is as per a two-pillar methodology that reflects the objective and subjective aspects of life and development in a Smart City. The first pillar is the physical infrastructure of cities, such as transport, healthcare, education and security. This is a basic prerequisite for the functioning of cities. The second pillar is technology, specifically digital services, e-government, mobile applications, and data transparency. This is the city's ability to use technology to solve residents' problems.

However, it is not enough to simply monitor technological advances and the development of local governments. Within the Smart City Index, it is crucial that the solutions provided are understandable, accessible and actually used in everyday life. Therefore, the assessment also includes a reflection on the subjective perception of the issues by residents. Local government residents assess the availability, quality and usability of city services. User-friendliness, digital inclusion and open communication are essential to ensure that technological innovations do not become merely a formal element of development.

In the IMD Smart City Index (see Table 1.5), European cities have long been recognised as major players in digital transformation, innovative urban management and sustainable development.

Among European cities, cities outside the European Union, namely Zurich (Switzerland) and Oslo (Norway), are stable leaders in the application of Smart City tools. During the period under review, they have remained at the top of the Smart City Index rankings. Their performance is the result of a long-term strategy in the area of digital transformation, high-quality infrastructure and a high level of public trust in public services. Both cities are examples of consistent development, where technological innovation is supported by effective governance and inclusive policies.

Europe's smartest city, Zurich, has long excelled in the areas of green transport, digital governance and open data. The city systematically invests in the modernisation of public services. It emphasises accessibility, transparency and user-friendliness, al. The high level of trust that residents have in public institutions is the result of a long-term policy focused on participation, inclusion and quality of life.

Oslo also emphasises sustainability, digital transformation and the interconnection of technological solutions with environmental goals. The city is developing intelligent transport systems, promoting green technologies and creating space for the active participation of residents in decision-making processes. The high level of digital literacy among the population and effective communication between the local government and citizens contribute to the city being perceived as one of the most progressive cities in Europe.

In addition to the stable leaders that have maintained their leading positions for a long time, smaller categories of developing cities have also been gaining ground in recent years. These are mainly Central and Eastern European metropolises, which, thanks to targeted strategies, investments in digital infrastructure and the active involvement of their residents, have managed to significantly improve their position in the rankings. These cities

Table 1.5

Smart City Index

| City | 2020 | 2021 | | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | rank | rank | ∨∧ | rank | ∨∧ | rank | ∨∧ | rank | ∨∧ | rank | ∨∧ |
| Zurich | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| Oslo | 2 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 |
| Helsinki | 6 | 5 | ∧1 | 5 | 0 | 8 | ∨3 | 9 | ∨1 | 11 | ∨2 |
| Copenhagen | 4 | 4 | 0 | 4 | 0 | 4 | 0 | 6 | ∨2 | 7 | ∨1 |
| London | 7 | 6 | ∧1 | 6 | 0 | 6 | 0 | 8 | ∨26 | 6 | ∧2 |
| Geneva | 10 | 9 | ∧1 | 9 | 0 | 9 | 0 | 4 | ∧5 | 3 | ∧1 |
| Lausanne | 9 | 8 | ∧1 | 8 | 0 | 5 | ∧3 | 7 | ∨2 | 10 | ∨3 |
| Amsterdam | 12 | 13 | ∨1 | 13 | 0 | 15 | ∨2 | 18 | ∨3 | 17 | ∧1 |
| Prague | 20 | 18 | ∧2 | 17 | ∧1 | 14 | ∧3 | 15 | ∨1 | 12 | ∧3 |
| Hamburg | 14 | 12 | ∧2 | 11 | ∧1 | 11 | 0 | 14 | ∨3 | 20 | ∨6 |
| Vienna | 30 | 28 | ∧2 | 26 | ∧2 | 28 | ∨2 | 23 | ∧5 | 26 | ∨3 |
| Tallinn | 40 | 38 | ∧2 | 35 | ∧3 | 32 | ∧3 | 24 | ∧8 | 22 | ∧2 |
| Vilnius | 60 | 58 | ∧2 | 55 | ∧3 | 65 | ∨10 | 47 | ∧18 | 34 | ∧13 |
| Ljubljana | 50 | 48 | ∧2 | 45 | ∧3 | 47 | ∨2 | 32 | ∧15 | 16 | ∧16 |
| Bratislava | 70 | 68 | ∧2 | 65 | ∧3 | 62 | ∧3 | 56 | ∧6 | 57 | ∨1 |
| Berlin | 25 | 23 | ∧2 | 22 | ∧1 | 33 | ∨11 | 37 | ∨4 | 37 | 0 |
| Brussels | 28 | 26 | ∧2 | 25 | ∧1 | 35 | ∨10 | 40 | ∨5 | 48 | ∨8 |
| Barcelona | 18 | 17 | ∧1 | 16 | ∧1 | 75 | ∨59 | 81 | ∨6 | 92 | ∨11 |
| Milan | 22 | 21 | ∧1 | 20 | ∧1 | 82 | ∨62 | 91 | ∨9 | 97 | ∨6 |
| Paris | 15 | 14 | ∧1 | 13 | ∧1 | 46 | ∨33 | 49 | ∨3 | 71 | ∨22 |
| Madrid | 35 | 34 | ∧1 | 33 | ∧1 | 37 | ∨4 | 35 | ∧2 | 38 | ∨3 |
| Warsaw | 50 | 48 | ∧2 | 46 | ∧2 | 44 | ∧2 | 38 | ∧6 | 28 | ∧10 |
| Riga | 90 | 85 | ∧5 | 80 | ∧5 | 83 | ∨3 | 59 | 24 | 46 | ∧13 |
| Sofia | 110 | 108 | ∧2 | 105 | ∧3 | 111 | ∨6 | 113 | ∨2 | 121 | ∨8 |
| Bucharest | 105 | 103 | ∧2 | 100 | ∧3 | 104 | ∨4 | 100 | ∧4 | 78 | ∧22 |
| Zagreb | 115 | 112 | ∧3 | 110 | ∧2 | 106 | ∧4 | 102 | ∧4 | 85 | ∧17 |

Source: own processing as per IMD (2020-2025)

prove that it is possible to compete with more developed Western European cities if a well-thought-out, targeted strategy is chosen.

One example of such a city is Ljubljana (Slovenia). The Slovenian capital has moved up from 50th place in 2020 to an impressive 16th place in 2025. It achieved this 34-place jump thanks to the development of green mobility, expanded access to open data and support for participatory planning. Thanks to open data and participation, the city has gained the trust of more than just its domestic population.

The situation is similar in Bucharest (Romania). The city moved up from 105th place to 78th place. The city benefited from improvements in the digitisation of public administration and the development of digital services, which significantly increased the efficiency of communication between citizens and the authorities.

Zagreb (Croatia) has also made significant progress. The metropolis moved up 30 places, from 115th to 85th. The modernisation of public transport, the introduction of intelligent transport systems and the digitisation of city services contributed to an increase in resident satisfaction, which had a significant impact on the city's overall rating.

Vilnius (Lithuania) moved up from 60th to 34th place. The city's progressive growth and development is as per its start-up ecosystem. This ecosystem supports technological innovation, entrepreneurship and digital solutions in the field of public services. The city also emphasises digital inclusion, which is why modern technologies are available to a wide range of residents.

Warsaw (Poland) has also seen significant growth and progress. It moved up from 50th to 28th place thanks to the development of intelligent transport systems, sensor networks and urban data platforms, which have significantly improved urban mobility and environmental control.

A dramatic decline has been recorded in several major European cities. Paradoxically, these cities were among the most technologically progressive in previous years. Their fall in the Smart City Index ranking highlights the risks associated with stagnation, insufficient updating of digital services and a weakening of residents' trust in public administration. This highlights the need for continuous innovation in digital services, monitoring of user experience, and active involvement of residents in the urban development process. Technological sophistication alone does not guarantee that cities will maintain their position in the rankings. What matters is how technologies are integrated into everyday life, how they are perceived by citizens, and whether they can respond to their real needs. Without regular updates, user-friendliness, and open communication, even a technologically advanced city can lose its position among the leaders of smart development.

Milan (Italy) recorded the most significant decline. Its drop of 75 places (from 22nd to 97th) was caused by its inability to keep up with technological standards, which led to a loss of trust among residents. The absence of a strategic approach to digital transformation and a decline in satisfaction with available services significantly affected the overall perception of the city.

Barcelona (Spain) also recorded a significant decline. It fell from 18th place to 92nd place in 2025 (a drop of 74 places). This dramatic decline is the result of several systemic problems that have manifested themselves in a deterioration in residents' perception of city services. Inadequate updating of digital platforms, limited availability of modern technologies and poor user experience have contributed to a loss of trust in public administration.

The example of Paris (France) is also surprising. Its drop from 15th to 71st place in the Smart City Index ranking is mainly due to growing criticism in the areas of transparency, limited availability of digital services and the

slow pace of innovation. The city has failed to adapt effectively to new digital challenges that require flexibility, openness and the ability to respond to the changing needs of residents. Another fundamental problem was the poor coordination between individual city platforms, which led to fragmentation of services and a reduced user experience.

The case of Paris shows that even cities of global importance are not immune to stagnation if they fail to keep pace with technological developments and reflect the expectations of their residents.

## 1.5 Summary

The absence of a uniform definition of a Smart City leads to interpretative dispersion, which manifests itself in the diversity of approaches taken by the private sector, local governments, academia and civil society. Reducing the concept to technological determinism is considered a conceptually outdated paradigm. Promoting an interdisciplinary approach that includes social innovation, ethical impact assessment and strategic planning is currently essential for the development of local governments and society.

The Smart City concept thus represents a paradigm shift in the understanding of urban development, which goes beyond traditional technological frameworks and moves towards a holistic, value-oriented and inclusive model of urban environment management. Smart City represents a dynamic urban ecosystem integrating modern information and communication technologies, participatory decision-making, environmental sustainability and social inclusion.

Smart City is a system management tool that enables cities to respond flexibly to changing conditions, allocate resources efficiently and plan sustainable development as per data-driven decisions. In this context, the Smart City concept takes on strategic importance because it links

technological innovation with public policy, community involvement and environmental responsibility. Its multidimensional nature allows it to integrate various areas of urban life, from infrastructure and the economy to social inclusion, into a unified framework that supports the quality of life of residents.

In this context, Smart City can therefore be seen not only as a technological project, but also as a socio-political project that reflects the need for democratisation of decision-making processes, inclusion and strategic planning. This broader interpretation is fully in line with the principles and objectives of Agenda 2030, to which the Slovak Republic also subscribes.

# CHAPTER 2. SMART GOVERNMENT - DATA-DRIVEN UNDERSTANDING

In an urban context, Smart Government is becoming a fundamental pillar for shaping an inclusive, effective and adaptive environment. Local government units are naturally becoming more adaptable and effective ecosystems than ever before. Smart technologies such as sensors, the Internet of Things and data platforms are tools through which cities are transforming into intelligent organisms. Cities are becoming not only technologically advanced, but also socially inclusive and environmentally sustainable. The result is an urban environment capable of continuous learning, adaptation and innovation.

Data-driven self-governing systems enable local authorities to better understand the needs of the community, respond to them in real time and anticipate future challenges.

Transparent information sharing, open communication channels and participatory tools create space for dialogue, trust and cooperation. Smart Government is thus no longer just a technical concept, but a relationship in which technology becomes a bridge between citizens and the city.

In the context of digital transformation, Smart Government represents a paradigm shift from the traditional model of governance to a sophisticated model of dynamic interaction. Data-driven self-governing systems thus become not only a tool for optimisation, but also a mechanism for collective awareness and knowledge.

## 2.1 Smart Government - synergy of relationships and empathy algorithms

In the relationship between the city and its citizens, public administration issues are shifting from static structures to dynamic models of cooperation. The characteristic features of this model are participation (MIRRI, 2019), transparency and value-oriented decision-making. This new type of public administration moves away from algorithms as per the consolidation of power. The current model supports the development of the relationship between citizens and local government, thereby acquiring the character of a reflexive and empathetic system. Technology is no longer the dominant determinant of direction. On the contrary, it is beginning to serve values that shape the common good. Local governments must embrace network thinking and community collaboration, which is in line with the principles of local government (Krellmann, 2025).

For the successful implementation of smart governance, it is necessary to fulfil three basic sets of prerequisites:

- **Institutional prerequisites**, which include legislative frameworks, technological infrastructure, cyber security, system interoperability and digital awareness.
- **Organisational prerequisites**, which focus on the transformation of internal processes, harmonisation between local government departments and identification with the principles of smart governance.
- **Leadership prerequisites**, which include strategic vision, long-term orientation, participation of relevant stakeholders, and knowledge sharing within local politics.

The systematic fulfilment of institutional, organisational and leadership

conditions enables cities to optimise the efficiency of urban operations, improve the quality of life of residents and support the economic growth of the unit. The essence of Smart Government therefore lies in the city's ability to combine technological possibilities with value-oriented decision-making (eEstonia, 2024).

Modern cities striving for Smart Government must guarantee not only the effective management of public services, but also the involvement of citizens in policy-making through participatory tools. Mutual learning and knowledge sharing strengthen the democratic legitimacy of decision-making processes.

Vaňová (2021) and Vitálišová et al. (2022) understand smart governance in cities as a complex and dynamic process that goes beyond technological modernisation. Given this, linking digital innovation with a value-oriented approach to public administration requires interdisciplinary competencies. The ability to work with data, understand technological possibilities, and sensitively perceive social and cultural contexts are becoming essential.

In their study, Dubravova & Bures (2023) highlight four elements of Smart Government:

- ***Services for people and communities:***
  - Digital public administration is characterised by transparency, efficiency and accessibility of local government.
  - Digital tools of local government ensure easier access to information, services and decision-making processes not only for the government itself, but also for its citizens.
  - eServices strengthen trust in local government institutions.
  - The openness of local government improves the quality of democratic governance of local government units.
- ***Innovative solutions vs. community cohesion:***
  - Innovative solutions contribute to deepening citizens' sense of

belonging to the territory and community.

- Community cohesion manifests itself in various types of structures and initiatives - neighbourhood initiatives, thematic communities, etc.
- Transparency of processes supports the formation of inclusive and sustainable communities of the future.

- ***Shared data and solutions:***
  - A tool for social integration and cohesion – emphasis on preventing the digital exclusion of localities.
  - Equal opportunities and strengthening inclusive access to services - cooperation between residents, representatives of local government units, communities, non-profit organisations and other actors in territorial development.
- ***Partnership as a platform for cooperation (local, regional, international cooperation):***
  - Cooperation with domestic and foreign partners - sharing best practices and smart solutions that support the interests of municipalities, cities and regions.
  - Exchange of knowledge, implementation of joint projects and formulation of digital development strategies that reflect local needs in a global context.

In current approaches to smart governance, municipal open data is emerging as a critical infrastructure for digital self-government. Municipal open data has the potential to bring greater transparency to decision-making processes, public policy planning and municipal resource management. The collection and use of data in urban infrastructure in the form of electronic city services helps to improve the quality of services for residents. Through data, cities can identify the real challenges of the area (Smart City, 2025).

Thanks to its ability to link data analysis with insights from public policy, planning and community development, city administration can respond effectively to today's challenges. These often go beyond technical solutions and require value-based decision-making that is sensitive to the needs of the community. For this reason, Smart Government fully applies the principles of openness, cooperation and shared responsibility. These principles enable cities to function as inclusive, adaptive and transparent ecosystems.

The current discourse on smart governance is focusing on the issue of citizens' trust in administration and digital public services. The issue of trust is becoming a key predictor of the success of the digital transformation of cities and communities. Citizens, as active, critically thinking subjects of the digital ecosystem of public administration, are becoming the bearers of dynamic feedback. Ultimately, this feedback helps shape technological solutions, legitimises decision-making processes and connects technical infrastructure with the value expectations of the community. On this basis, citizens become an integral part of the socio-technological architecture of smart governance.

In the context of the above, it appears that smart government cannot focus exclusively on the technical quality of the services provided. Emphasis must also be placed on the value dimension of services. The dynamics of joint interaction in a given space are important for the formation of public services that are not only effective but also meaningful in terms of the quality of life of residents. New dynamic forms of interaction between different entities thus stimulate the development of Smart Government.

Citizens' preferences in using digital public administration services are shaped by their transparency (Chohan & Hu, 2020), complexity and the ability of local governments to respond sensitively to the specific needs of the community. Examples of such services are mobile applications or the

use of artificial intelligence (AI). Mobile city applications allow citizens to easily submit suggestions, request services or track the status of their requests. This increases the comfort, transparency and efficiency of communication between local government and residents. Citizens do not have to visit the authorities in person, which saves time and reduces the administrative burden. Another interesting example is chatbots. Thanks to AI, chatbots can automatically answer citizens' most frequently asked questions, navigate them to the right information, or help them with simple tasks. AI provides citizens with information about current events, contact details for authorities, traffic restrictions and parking options. It operates 24 hours a day, significantly improving the availability of services. In addition, chatbots can be connected to municipal systems, enabling them, for example, to send notifications about service outages or accidents, collect feedback from citizens, secure appointments at government offices, and so on. (Trencin, 2020, Cebrova, 2019). The advantages of chatbots are their scalability, speed of response and ability to learn from interactions. This makes them an important tool in modern city management.

Citizens' trust in new eServices is not just a psychological prerequisite for the adoption of technologies (Hartanti et al., 2021). It is a systemic indicator of the quality of the institutional setting for the level of citizen participation and the ability of public administration to generate social value through digital innovation. In this context, it is essential that smart government does not focus its efforts exclusively on optimising service performance parameters, but actively cultivates trust as a strategic dimension of digital transformation.

One of the most comprehensive tools for measuring the progress of eGovernment at the local level. Created thanks to a UN (UNDESA) initiative, it is the Local Online Services Index (LOSI).

This index captures several criteria that it evaluates, as per information and services provided by local governments through official websites. LOSI is a multidimensional index that in 2024 includes 95 indicators divided into six main areas: institutional framework, content provision, service provision, participation and engagement, technological parameters, and a newly introduced digital literacy sub-index (see Table 2.6). Each of these areas has precisely defined criteria that allow cities to be compared across countries and cultural contexts.

Thanks to LOSI, we can monitor which cities are truly fulfilling the principles of digital democracy and which are merely digitising without deeper transformation.When it comes to applying the principles of Smart Governance, it is equally important to pay attention to the dimension of inter-municipal and cross-border cooperation. Smart Governance does not only mean the internal modernisation of processes within a single municipality, but also the ability to connect with other cities, coordinate strategies and share solutions that transcend local boundaries.

The European Union also supports the sharing of capacities, technologies and experiences. This support takes the form of a systematic framework through programmes such as URBACT, Intelligent Cities Challenge, Horizon Europe and Interreg. These initiatives enable cities to create thematic networks in which they jointly propose solutions aimed at digital transformation and increasing the inclusiveness of public services. Building common data platforms and interoperable systems, implementing joint public procurement, coordinating services for citizens across regions, sharing technical capacities and expertise, harmonising digital standards, creating joint open data strategies and strengthening territorial cohesion through interconnected innovation ecosystems are just a few examples of the practical implementation of smart governance principles.

Table 2.6
Local Online Service Index (LOSI)

| | |
|---|---|
| **Institutional framework** | Monitors whether the city has an e-government strategy, legislation on access to information, privacy protection, and an open data policy. These are basic prerequisites that monitor whether the city has an e-government strategy, legislation on access to information, privacy protection, and an open data policy. These are basic prerequisites that determine whether digital transformation is embedded in the legal and organizational system of local government. |
| **Content provision** | Monitors the extent to which basic information about services, citizens' rights, contacts, budgets, and public decisions is available online. This dimension reflects the transparency and openness of local government. |
| **Service provision** | Assesses whether specific services, such as applications, registrations, payments, or reservations, are available electronically. It monitors not only the existence of these services, but also their functionality, accessibility to different population groups, and integration with other systems. |
| **Participation and engagement** | Measures whether the city allows citizens to participate in decision-making, e.g., online consultations, voting, participatory budgets, or forums. This dimension is key to the democratization of digital governance. |
| **Technological dimension** | Monitors the technical aspects of city portals, their accessibility, navigation, design, compatibility with various devices, and accessibility standards. These are qualitative parameters that affect the user experience. |
| **Digital literacy** | Reflects the ability of residents, especially vulnerable groups, to use e-services. It assesses whether the city provides guidance, support, training, or other forms of assistance that enable inclusive access to digital tools. |

Source: UN (2024)

If smart governance is to be more than just a declaration, cities must start thinking regionally, acting collectively and connecting across Europe. Cooperation is not a weakness, but an intelligent strategy that enables cities

to transcend their limits, strengthen their resilience and become active players in shaping the future. In this dynamic, cities are transforming from administrative units into living hubs of European innovation, participation and sustainability (Smart City, 2025).

Therefore, we include the following among the attributes of Smart Governance (Vinod Kumar et al., 2020):

- A Smart City practices accountability, responsiveness, and transparency in its governance.
- A Smart City uses big data, spatial decision support systems and related geospatial technologies in urban and city governance.
- A Smart City constantly innovates e-governance for the benefit of all its residents.
- A Smart City constantly improves its ability to deliver public services efficiently and effectively.
- A Smart City practices participatory policymaking, planning, budgeting implementation, and monitoring.
- A Smart City has a clear sustainable urban development strategy and perspectives known to all.
- A Smart City utilizes creative urban and regional planning with a focus on the integration of economic, social, and environmental dimensions of urban development.
- A Smart City features an effective, efficient, and people-friendly urban management.
- A Smart City practices E-Democracy to achieve better development outcomes for all.

## 2.2 Examples in the area of Smart Government

Cities around the world are increasingly focusing on the use of digital technologies to optimise public services, support environmental goals and improve the quality of life of their residents. This process is accompanied by fundamental changes in approaches and initiatives to governance. Several European countries have adopted national strategies that define the principles of governance in the context of Smart Cities. A key element of success is balancing technological efficiency with ethical responsibility, inclusion, and public trust.

***Oslo, Finland – minimalism in decision-making, maximalism in data***

Oslo is an exceptional example of modern urban management that has managed to overcome traditional administrative barriers. It is considered one of the most advanced European cities in smart data management, as confirmed by the OECD Smart City Data Governance report (2023). City management in Oslo is characterised by a high degree of horizontal coordination. Individual local government departments work together on the basis of common data standards and objectives. As a result, the issue of fragmentation of competences, which is typical of many European cities, is a thing of the past.

Public services are designed and provided as per the real needs of residents, identified through data analysis and digital consultations (Marino et al., 2024). The active involvement of citizens in the creation of digital services is a matter of course. In addition, it uses open data. The Open Data Oslo platform makes city data available to developers, researchers and the public, promoting transparency and innovation.

Oslo is one of the first cities to use artificial intelligence to optimise services (See Table 2.7). It is considered a leader not only in terms of the use

of artificial intelligence, but also in terms of the systematic application of ethical principles in working with it. In the area of city management, it also uses AI for algorithmic decision-making, which is subject to transparent oversight. Oversight prevents the unintentional disadvantaging of certain population groups.

Table 2.7

eGovernance in Oslo - current pillars vs. future challenges

| **Pillars** | **Challenges** |
|---|---|
| Transparency of decision-making | Uneven citizen participation |
| Ethical principles of working with AI | Low interoperability of some platforms |
| Availability of online information – Open Data Oslo platform | Dependence on digital infrastructure |
| Data-driven services for residents | Ethical dilemmas in AI |
| Citizen participation – platforms | Digital fatigue among users |
| Personal data protection – prevention of discrimination | |

Source: own processing as per UN (2024), Oliveira et al. (2025)

The city uses various participatory platforms. Through these, residents can propose changes, evaluate existing services and co-create new digital tools. This approach increases public confidence in technological interventions and local government policies, as they are also the result of joint dialogue.

City services are not only digitised, but are actively co-created by the community, thereby strengthening their relevance, effectiveness and trust in city administration (Oliveira et al., 2025). This approach represents

a paradigm shift from technocratic governance to inclusive, transparent and data-driven city management.

In terms of its LOSI score (see Figure 2.2), Oslo has a well-established legal, organisational and strategic foundation for digital services, which is reflected in its maximum score in the institutional framework category. The quality and nature of the services provided are also rated positively, as is citizen participation, which indicates their engagement and willingness to participate in digital public administration processes.

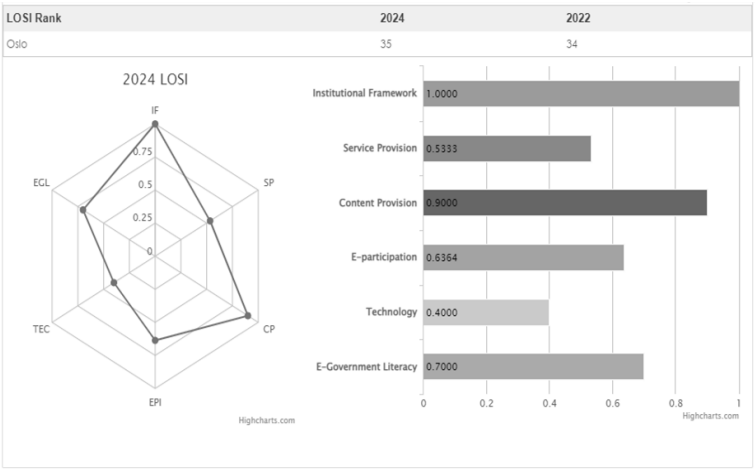



Figure 2.2

Oslo - Local Online Service Index (LOSI)

Source: UN (2024)

Oslo also scores highly in terms of content provision and digital literacy, which points to the ability of residents to make effective use of the available eServices. These results indicate that the city has laid a solid foundation for the further development of the digital society.

Future areas of interest should focus on expanding services and platforms, particularly in the context of personalisation, accessibility and inclusiveness of digital solutions. At the same time, emphasis should be placed on developing citizens' digital literacy, thereby strengthening their ability to critically approach digital content, communicate safely online and actively participate in digital democracy.

***Tallinn, Estonia - small city, big eLeader***

Estonia is internationally recognised as a leader in digital public administration. Smart governance is characterised by the extensive use of digital services and e-government platforms at both the state and local government levels. All public services in the country are digitised, including complex life situations (Männil, 2024). Citizens can electronically apply for benefits, pay taxes, access public transport information, manage health records and communicate with authorities without having to visit them in person.

The system is as per the principles of user-friendliness, security and transparency, with all services also available via mobile devices. Interaction with authorities and agendas, i.e. voting, sending proposals, providing feedback and communicating with city officials, is valid within the 24/7 model.

A key element of the Estonian Smart Government model is the effective sharing of data between municipal and state databases, which makes it possible to streamline administrative processes, reduce bureaucracy and improve the quality of services provided. A high level of cyber security is guaranteed by cooperation with the NATO Cooperative Cyber Defence Centre of Excellence (CCDCOE, 2023). The centre is located in Tallinn, which is referred to as the country's main digital laboratory.

In 2024, the United Nations (UN, 2024) declared Tallinn the best city in the world for the provision of digital public services. The city actively adopts new technologies to streamline municipal operations and digitise public services, making life more convenient. The city provides e-services not only for citizens and businesses, but also for visitors. All services are inclusive, easily accessible and secure. Personal data is protected to the highest standards.

In the area of civic participation, the city actively uses digital tools to involve residents in decision-making processes (See Table 2.8).

Table 2.8

eGovernance in Tallinn - current pillars vs. future challenges

| **Pillars** | **Challenges** |
|---|---|
| Transparency of decision-making – city dashboards, digital twin | Digital fatigue of users |
| Availability of online information | The "Big Brother" effect |
| Digital services for residents – e-identity | Digital illiteracy – migrants |
| Citizen participation | Automated decisions |
| Personal data protection | Cyber threats |

Source: Own processing as per Bogoni (2023), UN (2024), Schachtner (2025), IMD (2025)

The Estonian model shows that smart governance is not just about technology, but about a value-oriented approach to public administration, where technology serves people, not the other way around. Thanks to the combination of digital innovation, open data and participatory

mechanisms, Estonia has become a model for many countries seeking to modernise their public administration.

Public opinion polls are systematically used as a first step in planning public projects, interventions, investments, and community projects. The aim is to obtain qualitative and quantitative data on residents' needs and reflect them in strategic planning. Data analysis is an integral part of the design of city services. In addition, the data obtained becomes part of a broader open data system. The city makes the data openly available to the public (Jakonen, 2024). It allows residents to make their own decisions as per it, e.g. about housing, business or activities in the area.

The strategic goal of the city of Tallinn is to generate social value by providing high-quality, accessible and efficient public services (Sarv & Soe, 2021, Julsrud & Krogstad, 2020). The city's services are designed and provided according to the principle of service design, i.e. services are people centred. The service design itself is user-friendly, relevant and valuable to the user. The relevance and compliance with service requirements is reviewed annually and services are redesigned as necessary. Systematic feedback from citizens and stakeholders is an integral part of the service evaluation and improvement processes.

In this context, attention is also paid to employees. Employees are expected to actively participate in shaping a positive image of the city. Every representative of the city organisation (from managers to employees) respects the principles of transparency, accountability and ethical behaviour (Tallin, 2025).

Employees must therefore contribute to shaping a positive image of the city and represent the values of the local government unit. Employees are encouraged to take reasonable risks, assume responsibility and reflect on their activities.

In terms of the LOSI score achieved (see Figure 2.3), Tallinn has an excellent legal and organisational framework, which is reflected in the maximum rating in the institutional framework category. The digital content of services is rated as high quality, ensuring high information value and accessibility for citizens. An equally high score in the area of digital literacy indicates that residents are able to use digital tools and services independently and effectively.

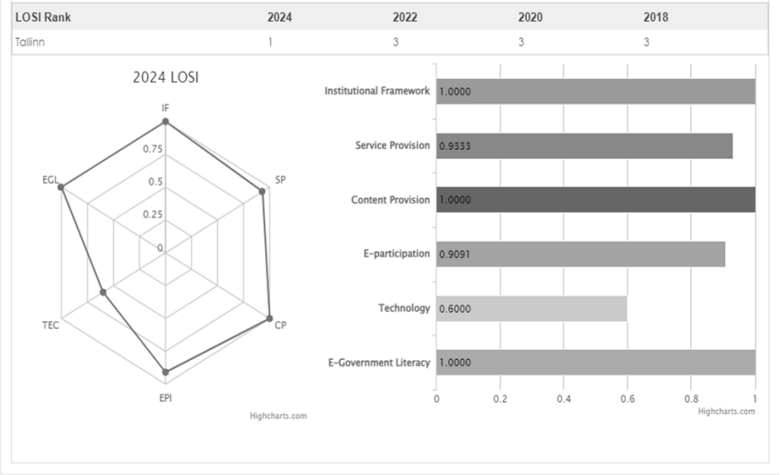



Figure 2.3

Tallinn - Local Online Service Index (LOSI)

Source: UN (2024)

Tallinn also scores highly in the categories of e-participation and service delivery, indicating active citizen participation in digital processes and a well-functioning e-government system. Nevertheless, the area of technological infrastructure scores lower, indicating room for further development in innovation, automation and the integration of advanced technologies.

Future areas of interest should therefore focus on promoting digital reskilling, particularly in the context of a rapidly changing technological environment, and the ethical use of artificial intelligence (AI), which will play a key role in the transparency, trustworthiness and inclusiveness of digital services.

***London, United Kingdom – tradition crowned with innovation***

The transformation of the United Kingdom into a modern digital landscape full of innovation is proof that even a country with deep historical roots can respond flexibly to the challenges of the present, connect tradition with technology and build the future. Since 2010, the British government has been promoting the digitisation and electronisation of services, which are thus intended to be customer-friendly and accessible.

Thanks to centralised platforms such as GOV.UK, the United Kingdom is becoming an example of how technological innovation in government services can be inclusive, transparent and culturally anchored. Simplicity and security are among the main requirements for their new form.

The systematic digitisation of administration, linking technological innovation with a value-oriented approach to public administration, is also part of the strategy of the capital city – London. London is thus profiling itself as a model metropolis that uses digital tools not only to streamline administrative processes (Gupta et al., 2020), but also to strengthen democratic principles, social equality and civic participation.

The pillars of a comprehensive framework for the development of smart governance, which combines technological innovation with a value-oriented approach to public administration, are (GOV.UK, 2025):

1. **Digital inclusion** - digital services available to all residents, regardless of age, ability, language skills or social background.

Through the Digital Inclusion Innovation Fund, the city supports projects that aim to reduce digital inequality, increase trust in digital public services and promote innovative measures.

2. **Open data and transparency** - the London Datastore platform (see Figure 2.4) makes thousands of data sets freely available to a wide range of clients, e.g. citizens, entrepreneurs and researchers. Datasets on transport, the environment, housing and health strengthen trust in local government and enable participation in its activities. Datasets support the creation of new applications, analytical tools and services.


Figure 2.4
London Datastore - portal
Source: London Datastore (2025)

3. **Cooperation with the community and businesses** - partnerships between city administration, technology companies, the academic sector and civil society. The London Office of Technology and Innovation (LOTI) initiative supports the co-creation of digital solutions that respond to the real needs of residents (Kadiri et al., 2023) and increase the efficiency of public services (e.g. social care, professional development, etc.).

4. **Ethical use of technology** - emphasis on the need for an ethical framework when using artificial intelligence, sensor systems, data analytics and digital services. The framework is designed to ensure that technological development is carried out in accordance with the principles of transparency, accountability and privacy protection. The city actively supports the development of technologies that respect human rights and democratic values while minimising the risks associated with automated decision-making, data misuse and discrimination.
5. **User-oriented digital services** - simplicity, accessibility, efficiency and intuitiveness. The city is investing in the automation of administrative processes, simplifying forms and increasing the accessibility of services via mobile devices.

Table 2.9 highlights the contrast between the current pillars of eGovernance and the future challenges that need to be addressed.

Table 2.9

eGovernance in London - current pillars vs. future challenges

| **Pillars** | **Challenges** |
|---|---|
| Transparency of decision-making - city dashboards | Uneven participation – low |
| Availability of online information – London Datastore platform | Engagement in some neighbourhoods |
| Advanced digital services for residents | Political polarisation |
| Resident participation – community platforms | Cyber threats |
| Personal data protection – strong regulatory framework | Low platform interoperability |

Source: Own processing as per Tekin & Dikmen (2024), UN (2024), OECD (2023)

In terms of the LOSI score achieved (see Figure 2.5), London has built a strong strategic and legal foundation for digital services, which is reflected in the maximum rating in the institutional framework category. High scores in the areas of content provision and digital literacy among residents indicate that citizens are able to actively use available e-services and navigate the digital environment.

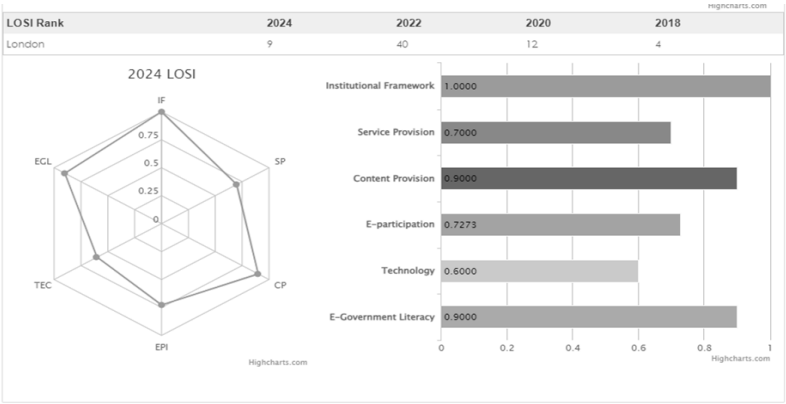



Figure 2.5

London - Local Online Service Index (LOSI)

Source: UN (2024)

At the same time, London is characterised by a solid level of citizen participation and service provision, which points to a functional system of interaction between public administration and users. Nevertheless, the area of technological infrastructure scores lower, indicating a need for further investment in the modernisation of technical solutions, system interoperability and the use of innovative technologies.

Future areas of interest should therefore focus on developing interactive platforms that support two-way communication and participation, as well as

strengthening the technological base to ensure greater efficiency, accessibility and inclusiveness of digital services in the city.

***Bratislava, Slovakia - in tune with technology and innovation***

In recent years, the Slovak Republic has also been increasingly moving towards smart governance. In the context of global trends in digitalisation and technological transformation of the public sector, it emphasises transparency in public affairs, effective use of data and citizen participation in decision-making processes. This approach reflects the need to modernise public administration, increase public trust and strengthen democratic mechanisms.

The capital city of Bratislava is not lagging behind in this regard, quite the contrary. Bratislava is becoming an active player in the implementation of Smart City principles. The conscious introduction of smart solutions places it among the cities that not only respond to the current challenges of urbanisation, climate change and technological progress, but also shape the future of sustainable, inclusive and smart local government.

One of the main pillars of smart governance in Bratislava is the digitisation of public services, which is a basic prerequisite for the effective functioning of a modern city. The introduction of digital platforms has given residents access to services that are accessible, transparent and user oriented. Key functionalities include:

- electronic submission of applications without the need to visit the office in person,
- the ability to monitor administrative processes in real time,
- active public participation through tools such as participatory budgeting, public consultations and digital voting.

Like many other global cities, Bratislava recognises the strategic value of data. It sees data as a tool for informed decision-making, trend prediction

and public policy optimisation. Open data and GIS systems are used to collect and manage data. These support the planning and management of city services (Bratislava, 2025).

City data is systematically categorised and made available according to authorisation levels. Three main groups have access to it: the general public, partner institutions (e.g. research centres, universities, technology companies) and the local government itself, which uses it for internal planning, monitoring and performance evaluation.

In line with the *Bratislava – Smart City 2030* concept, the city focuses on effective land management as per an integrated management and control system and open data management. Institutional support for this agenda is anchored within the city's own organisational structure. A key element is intelligent data management, which includes:

- review of existing data sources,
- processing of spatial data using GIS technologies,
- creation of structured databases according to data categories,
- setting up access to data (internal, public, partner),
- defining rules for data content, structure, timeliness and security,
- sharing via an internet platform.

As part of its efforts to increase management efficiency, Bratislava is building a unified management and control platform (Smart City, 2024, Ursache et al., 2023) that integrates all city information into a single system. This system represents the technological backbone of the city and enables (Yehorchenkova et al., 2023):

- decision-making as per accurate, up-to-date and validated data,
- visualisation of trends, statistics and performance indicators in an intuitive form,
- real-time monitoring and management of urban technologies

(e.g. lighting, transport, waste management).

Part of this transformation is the introduction of an integrated territory control system that uses modern technologies for data collection and monitoring of the urban environment. An important component is the integrated information system and open data system (see Figure 2.6), which ensures data communication to citizens, including access to spatial information via an online portal and data sharing in the public space in the form of a City Dashboard – a city management and information portal (Bratislava, 2022).


Figure 2.6

Bratislava - Open Data

Source: Bratislava (2025)

In the area of e-government services, Bratislava is focusing on expanding eGovernment tools. These enable simplified and remote access to services through information and communication technologies.

According to research by Yehorchenko et al. (2024), Bratislava is an example of a city that is systematically seeking to implement Smart City

principles in favour of sustainable development, ecological balance and improving the quality of life of its residents. This approach includes not only technological innovation, but also a social dimension. The emphasis on inclusion, equal access to services and the promotion of digital literacy is a matter of course.

Bratislava is gradually transforming into a dynamic territorial unit with a dynamically functioning administration that is data-driven and citizen-oriented. By applying this model, it is becoming a capable and flexible local government that can respond to the challenges of the present while creating conditions for long-term prosperity.

Table 2.10 highlights the contrast between the current pillars of eGovernance and the future challenges that need to be addressed.

Table 2.10

eGovernance in Bratislava - current pillars vs. future challenges

| **Pillars** | **Challenges** |
|---|---|
| Transparency of decision-making – City Dashboard | Fragmentation of data systems – inconsistent sources of integration |
| Availability of online information | Low digital literacy among residents |
| Digital services for residents | Uneven engagement – low participation in some locations |
| Citizen participation – participatory budgets | Cyber threats |
| Personal data protection – security | Low platform interoperability |

Source: Own processing as per Ursache et al. (2023)

In terms of the LOSI score achieved (see Figure 2.7), Bratislava shows balanced development in the area of digital public service management.

A strong rating in the institutional framework category indicates that the city has a stable strategic and legal basis for implementing eGovernment solutions. The high score in the area of content provision and digital literacy is also positive. This indicates the ability of residents to navigate the digital environment and actively use available electronic services.

On the other hand, service provision scores lower than the other areas assessed. This indicates a need to improve the practical accessibility of digital services and enhance the user experience.

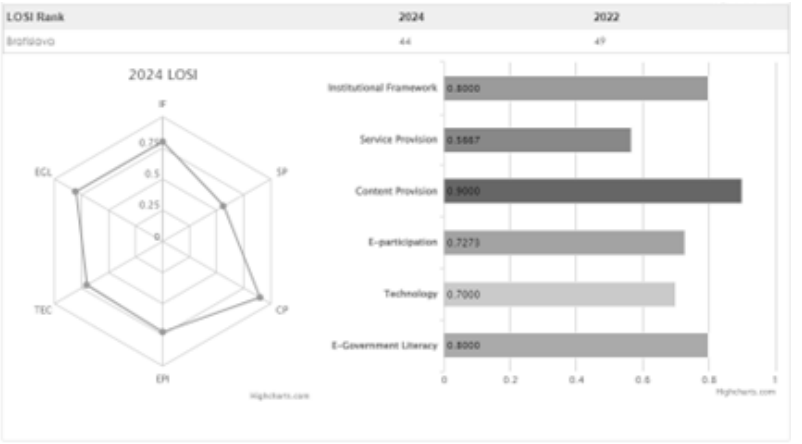



Figure 2.7

Bratislava - Local Online Service Index (LOSI)

Source: UN (2024)

Future priorities should therefore focus on building interactive platforms that support two-way communication between local government and citizens. Expanding services and strengthening the technological base could lead to increased efficiency, accessibility and inclusiveness of digital services in the city.

## 2.3 Summary

The concept of Smart Government represents a fundamental shift in the understanding of governance and service delivery. It is moving away from the traditional, hierarchical model towards a dynamic, participatory and data-driven ecosystem. Local governments are naturally transforming into living organisms that learn, adapt and innovate in real time. Technologies such as sensors, the Internet of Things, open data and urban digital platforms are no longer just tools for efficiency but are becoming a bridge between citizens and the city.

City projects demonstrate that smart governance is not just about technology, but above all about value-oriented decision-making, community participation and open cooperation. The successful implementation of Smart Government must be built on three fundamental pillars: institutional (legislation, digital infrastructure and cyber security), organisational (process transformation, interdisciplinary coordination) and leadership (vision, strategic planning, knowledge sharing and participation).

It is also important that cities do not neglect the value dimension of digital transformation. Technology must serve people, not the other way around. Citizens' trust, their digital literacy and the ability of local governments to respond to the specific needs of the community are key factors for success.

Smart Government is therefore not just about digitising services but about transforming the relationship between the city and its citizens.

# CHAPTER 3. SMART ECONOMY - THE NEW GENERATION ECONOMY

In today's environment, characterised by accelerating digitalisation, climate challenges and growing socio-economic inequality, city economies are becoming increasingly dependent on the ability to intelligently manage resources, innovate and build trust among actors in the urban ecosystem. The concept of the Smart Economy represents more than just the digitalisation of economic processes. It is a transformation of the economic model as per data, collaboration and sustainability. In this model, growth is defined not only quantitatively but also qualitatively. The ability of a city to generate value through innovation, entrepreneurship, knowledge and social capital is important in this area.

However, the basis of the Smart Economy is trust. Mutual trust between citizens, businesses and public institutions is a prerequisite for technological and economic innovations to be not only accepted, but also actively co-created and maintained. This trust is supported by transparency, open data and participatory mechanisms that enable the active involvement of all stakeholders in the creation and management of economic policies. This creates an algorithm of trust in which decisions are as per data but also reflect the values, needs and expectations of the community.

The Smart Economy is therefore a multi-layered concept that links technological innovation with inclusive growth, digital infrastructure with the business environment, and economic performance with environmental and social sustainability. In this context, cities are becoming not only centres of production and consumption, but also laboratories for new economic models capable of responding to the challenges of the 21st century.

## 3.1 Smart Economy - intelligence of growth and algorithm of trust

Over the last decade, the concept of the Smart Economy has established itself as one of the key pillars of economic transformation in the context of globalisation, digitalisation and climate challenges. At its core is the ability of economic systems to leverage digital technologies, innovation potential and human capital to create sustainable, inclusive and competitive growth. As Kovalchuk et al. (2024) point out, the development of the Smart Economy is not only a response to technological change, but also a strategic response to the need for a new model of economic development as per knowledge, flexibility and responsibility.

The Smart Economy is not just a technological phenomenon. As Treiblmaier (2017) emphasises, "the smart economy is not just about technology, but about society's ability to learn, adapt and collaborate".

One of the most important aspects of the Smart Economy is its potential to contribute to sustainable development. It therefore represents a shift from traditional growth models to networked, adaptive and data-driven systems. In this sense, it is closely linked to concepts such as the digital economy, the green economy and the circular economy, integrating them into a single framework as per the intelligent use of resources and the ability to respond to the challenges of the 21st century (Dutta et al., 2017).

According to Schwab (2016), the Smart Economy appears to be a natural consequence of the digitisation of production, process automation, the development of the Internet of Things (IoT), artificial intelligence (AI), blockchain and other technologies that are changing the way value is created, distributed and consumed. As Ghosh (2017) points out, smart technologies can significantly reduce the environmental footprint of the economy, for example by optimising energy consumption, reducing waste, promoting

circular models of production and consumption, and developing green innovations.

Treiblmaier (2017) points out that one of the main features of the Smart Economy is the ability to connect technologies with business models through digital platforms that enable new forms of collaboration, sharing and innovation. In other words, the Smart Economy is "*an economic system that uses information and communication technologies (ICT) to increase productivity, efficiency and competitiveness, while promoting social inclusion and environmental* sustainability" Treiblmaier (2017). Moreover, by being as per knowledge, digital technologies and creative industries, it becomes an engine for sustainable growth (OECD, 2020; European Commission, 2021).

According to research by Kovalchuk et al. (2024), the Smart Economy is as per the synergy of three key elements, namely technological readiness, innovation capacity and social inclusion (Treiblmaier, 2017):

- ***Digital infrastructure*** - includes high-speed networks, cloud services, data centres and other technological foundations that enable the digital economy to function. Without a robust and secure infrastructure, it is not possible to develop smart business or public services.
- ***Innovation ecosystem*** - consists of a set of actors (companies, universities, research institutions, start-ups) who collaborate on the development of new products, services and processes. A key element is the ability to connect knowledge, capital and entrepreneurial skills in an environment that supports experimentation and rapid adaptation.
- ***Entrepreneurial culture and human capital*** - the Smart Economy requires a new generation of workers who are digitally literate,

creative and capable of lifelong learning. It also promotes entrepreneurial thinking, openness to change and the ability to collaborate in multidisciplinary teams.

However, competitiveness in the Smart Economy is not just a matter of national strategies, but also of the ability of cities, regions and communities to create smart ecosystems. These actors are key to strengthening the economic sustainability of communities and fulfilling the objectives of the Smart Economy concept. Their active involvement in strategic planning and public policy implementation enables the effective linking of national sectoral policies with local needs.

Local governments are the drivers of initiatives to stabilise jobs through the development of technical, transport and research and development infrastructure, which enables the valorisation of local human and natural capital. Local governments play an irreplaceable role in supporting new forms of employment, developing the sharing economy and promoting social entrepreneurship. In the context of regional resilience to external shocks, local governments play an important role in closing production cycles, thereby strengthening their self-sufficiency and economic stability.

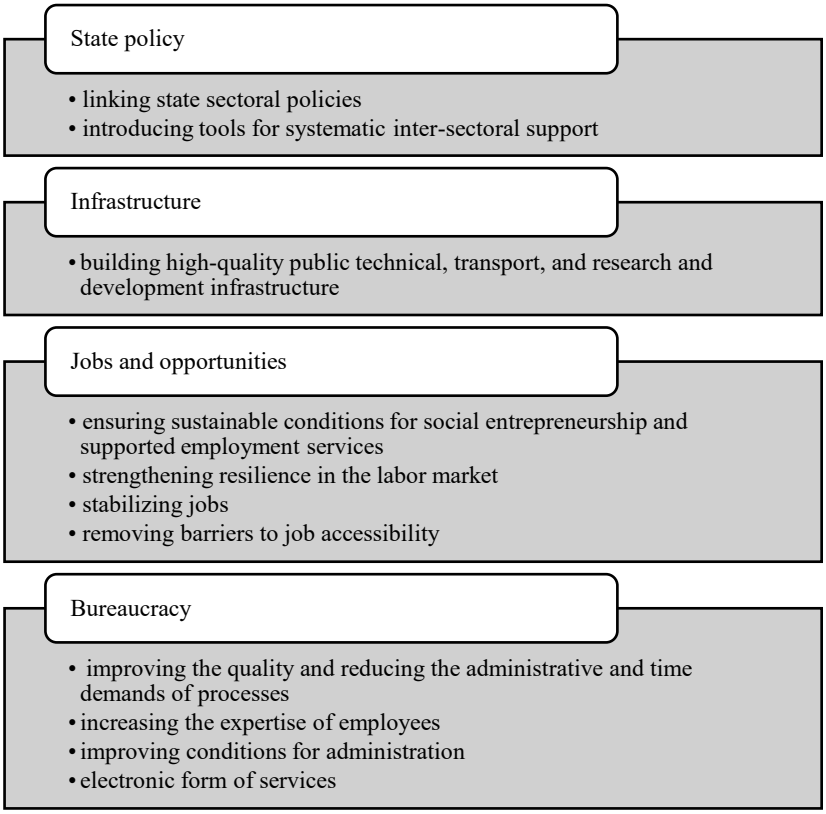
Another important aspect is improving the quality of public services through digitalisation, process standardisation and participatory planning. The development of regional and local strategies in cooperation with citizens and the wider public is a further step towards enabling local governments to respond effectively to current challenges and shape a sustainable economic future for their communities (see Table 3.11).

As stated by Kalenyuk et al. (2021), the phenomenon of "*glocalisation*" – i.e. the interconnection of global trends with local solutions – is gaining ground in the global environment. In this sense, the Smart Economy supports the creation of regional innovation clusters, digital hubs and business

platforms that are able to respond to the specific needs of the population while participating in global value chains.

Table 3.11

Smart Economy - strengthening the economic sustainability of local governments




Source: own processing as per MIRRI, 2020

As one of the main pillars of Smart City, Smart Economy is also a central element of the economic, social and cultural development of the urban ecosystem. According to Siokas and Tsakanikas (2023), it is an attractive

environment for the creation of new businesses, the support of incubators, cooperative joint ventures and collaboration with university research groups. The Smart Local Economy is thus developing through competition, cooperation and the clustering of economic units that stimulate innovation.

One of the most striking manifestations of the Smart Economy is the emergence of new types of economic actors that operate on the basis of digital technologies, artificial intelligence and automation. As the BIP Group report (2024) shows, the advent of so-called virtual shopping agents represents a fundamental change in consumer behaviour, the functioning of retail and market structure. These systems can analyse customer preferences, compare offers in real time and make purchases without direct human intervention. The result is greater efficiency and personalisation of services, which is changing the traditional relationships between manufacturers, retailers and consumers.

The Smart Economy also has the potential to contribute to sustainable development. Intelligent technologies make it possible to optimise the use of resources, reduce environmental impact and promote circular models of production and consumption. Kovalchuková et al. (2024) emphasise that the Smart Economy is capable of integrating environmental, social and economic goals into a single framework, thereby creating the conditions for so-called "smart sustainability". This sustainability is not based solely on limiting growth, but on its qualitative transformation.

The Smart Economy is as per knowledge, data, digital technologies and the ability to respond quickly to the changing needs of society. Innovations in energy, mobility, public services and digital infrastructure enable cities to function more efficiently, sustainably and inclusively. At the same time, they create attractive job opportunities, support entrepreneurship and attract talent from home and abroad.

Education, digital literacy and human capital development also play an important role in this context. The Smart Economy requires a new generation of workers who are able to work with data, understand complex systems and collaborate in multidisciplinary teams. As Kalenyuk (2021) points out, investment in education and research is a key prerequisite for long-term competitiveness and social stability in a smart economy.

However, although the Smart Economy offers many opportunities, its implementation also brings several challenges. Among the most significant are:

- ***Digital inequality*** – differences in access to technology and digital skills can exacerbate social and regional disparities.
- ***Ethical dilemmas*** – the use of artificial intelligence, big data and algorithmic decision-making raises questions of transparency, accountability and privacy protection.
- ***Labour market transformation*** – automation and digitalisation are changing the structure of employment, requiring new forms of education and social protection.

In the long term, the success of the Smart Economy depends on the ability of local governments and society to strike a balance between innovation, inclusion and sustainability.

A new way of thinking and looking at land management is changing the established logic of isolated competition between local governments to a model of cooperation, coordination and sharing of solutions. Local government units are ceasing to function as competing entities. They are beginning to act as partners in joint territorial development. Local governments are increasingly profiling themselves as interconnected nodes in regional and European cooperation networks. In this context, inter-municipal and cross-border cooperation is becoming not a supplement but

a strategic tool for achieving truly smart governance. Supporting cooperation and networking between cities within the EU brings economic and social effects that fundamentally change the way units approach territorial management, innovation and public services.

Therefore, we include the following among the attributes of a smart economy (Vinod Kumar et al., 2020):

- A Smart City understands its economic DNA.
- A Smart City is driven by innovation and supported by universities that focus
- on cutting-edge research, not only for science, industry, and business but also for cultural heritage, architecture, planning, development, and the like.
- A Smart City highly values creativity and welcomes new ideas.
- A Smart City has enlightened entrepreneurial leadership.
- A Smart City offers its citizens diverse economic opportunities.
- A Smart City knows that all economics works at the local level.
- A Smart City is prepared for the challenges posed by and opportunities of economic globalization.
- A Smart City experiment supports and promotes the sharing economy.
- A Smart City thinks locally, acts regionally, and competes globally.
- A Smart City makes strategic investments in its strategic assets.
- A Smart City develops and supports compelling national brand/s.
- A Smart City insists on balanced and sustainable economic development (growth).
- A Smart City is a destination that people want to visit (tourism).
- A Smart City is nationally competitive on selected and significant factors.

- A Smart City is resourceful, making the most of its assets while finding solutions to problems.
- A Smart City excels in productivity.
- A Smart City has high flexibility in the labour market.
- A Smart City welcomes human resources that enhance its wealth.
- A Smart City's inhabitants strive for sustainable natural resource management and understand that without this its economy will not function indefinitely.

## 3.2 Examples in the field of Smart Economy

Cities around the world are increasingly looking for ways to strengthen their economic sustainability through smart solutions. The smart economy as a dimension of Smart City development focuses on the efficient use of public resources, support for the business environment, the development of digital services and the linking of economic activities with the principles of sustainability.

***Vienna, Austria - a waltz of economic sustainability***

The city of Vienna is one of the leaders in the field of Smart Economy. It places emphasis on the long-term economic sustainability of local government. It implements its strategy through integrated investment planning, the use of digital tools and the linking of development policies with climate and social goals. One of the most striking examples is the use of an advanced 3D geospatial digital model, known as a digital twin (Brooks, 2023). This tool allows the city to simulate investment scenarios, predict their impact on infrastructure, mobility, energy and the environment, and coordinate public and private investment (See Figure 3.8). This enables Vienna to allocate resources efficiently, reduce budgetary risks and optimise expenditure in real time. Digital planning is the practical implementation

of smart economy principles, where technology serves as a tool for increasing return on investment and transparency in decision-making processes.

This approach is also firmly anchored in the strategic document Smart City Wien Rahmenstrategie 2019–2050 (Wien, 2019). The document defines the principles of integrated planning of urban investments across sectors such as transport, housing, energy and digital infrastructure. Decision-making is as per data analysis, long-term sustainability and links to climate goals. Vienna thus combines economic growth with environmental responsibility, thereby strengthening its financial stability and ability to respond to future challenges.


Figure 3.8
Digitálny model - 3D digital twin
Source: Aspern (2025)

***Helsinki, Finland - in the service of economic sustainability***

The Business Helsinki initiative is a strategic tool of the City of Helsinki. It serves as a municipal agency to promote entrepreneurship, innovation,

investment and employment. Through this initiative, the city creates favourable conditions for business development and sustainable economic growth in the region. At the same time, it provides free advisory services to start-ups, start-ups and international companies (Helsinki, 2025). It assists with company registration, finding financing, networking and market expansion.

The city understands that economic vitality is the foundation of quality of life, sustainability and global competitiveness. Through Business Helsinki, it actively increases the city's attractiveness to talent and companies, thereby strengthening its position as a centre of innovation and entrepreneurship.


Figure 3.9

Business Helsinki portal

Source: Helsinki (2025)

It supports technological and social innovations that respond to current urban challenges such as climate change, digitisation of services and smart mobility. At the same time, it strives to strike a balance between economic

growth and environmental sustainability, thereby creating conditions for inclusive and long-term sustainable development of the city.

Business Helsinki (See Figure 3.9) represents a modern approach to urban management, in which economic development is not viewed in isolation but as part of a complex system that includes environmental, social and technological dimensions. Thanks to this initiative, Helsinki is profiling itself as a city that can link strategic visions with practical tools while creating space for inclusive and sustainable growth.

## 3.3 Summary

The Smart Economy concept is more than just the technological modernisation of the economy. It is a holistic framework for economic transformation that connects digital innovation, the business environment and social inclusion into a single synergistic whole. In the context of accelerating digitalisation and socio-economic challenges, cities and regions are becoming key players in economic change. The Smart Economy provides them with the tools to transform themselves from passive administrative units into proactive, adaptive and competitive ecosystems.

This transformation is as per the intelligent use of data, digital technologies and human capital. The Smart Economy is built on three pillars: digital infrastructure, an innovative ecosystem and an entrepreneurial culture that supports lifelong learning and creativity. These elements enable cities not only to optimise their processes, but also to create new forms of value that are environmentally sustainable and socially inclusive.

Once again, trust as per transparency, open data and participatory mechanisms is a key prerequisite for the successful implementation of the Smart Economy. In this environment, economic innovation becomes a joint effort of the public, private and civic sectors.

Challenges that should not be underestimated in the Smart Economy include digital inequality, ethical dilemmas associated with the use of artificial intelligence, and the transformation of the labour market. The success of the Smart Economy therefore depends on the ability of local governments to strike a balance between innovation, inclusion and sustainability. In the long term, the Smart Economy appears to be a key tool for building resilient, inclusive and competitive cities.

# CHAPTER 4. SMART LIVING - SMART SOLUTIONS FOR MODERN LIVING

At a time when cities are becoming increasingly complex systems, attention is being paid not only to technical efficiency but also to the quality of everyday life. The concept of Smart Living represents a new way of thinking about urbanism, in which technology is not placed above people but at their service. In this context, the intelligence of urban life is manifested primarily in the city's ability to perceive, respond and coexist with its inhabitants.

Smart Living is about harmony between physical and digital space, between individual comfort and collective good. At its core is an algorithm of belonging. It is as per connecting personal preferences, community needs and city services.

Smart housing, a healthy urban environment, accessible services, inclusive public spaces and digital equality are all components that define Smart Living as the people-oriented pillar of Smart City. In this model, cities become environments for dignified, healthy and meaningful living, where technology becomes a tool for coexistence, not isolation.

## 4.1 Smart Living - the intelligence of life and the algorithm of belonging

Smart Living should be seen as a holistic approach to urban life that connects physical infrastructure with digital services, social innovations and a cultural and educational environment. The fundamental goal of Smart Living is to create dynamic functional platforms that enable residents to actively participate in shaping the quality of life, economy and public space.

As Trencher (2019) states, Smart Cities should put people first and use technology primarily as a tool in the service of citizens.

As per research in the field of Smart Living, several lines of this concept can be identified. The key dimensions are the environmental aspect (Kahn, 2025, UN-Habitat, 2024, Kumar et al., 2020), the technological aspect, the social aspect (Junaidi et al. 2025, Pira, 2021), the economic aspect (FII, 2025) and the aspect of promoting a healthy lifestyle (Sulaiman et al., 2024). The Smart Living concept also includes the creation of liveable and safe cities (Smith et al., 2024, Cantuarias-Villessuzanne et al., 2021, Ligarsky & Wolny, 2021) that improve lives and address social challenges (Chen and Chan 2023, Toli and Murtagh 2020).

Cities consciously and proactively create a smart ecosystem that promotes inclusion, diversity and social cohesion. They create conditions for the emergence and development of educational institutions, cultural centres, community organisations and innovation hubs. This approach is in line with the principles of the Triple Helix Model (Etzkowitz & Leydesdorff, 2000), which emphasises cooperation between academia, the business sector and public administration as the basis for innovative development. More recent studies (Shyiramunda & van den Bersselaar, 2024, Stephens, 2025) extend this model to the Quadruple Helix, adding the local community as an active co-creator of innovation.

Cities are actively developing their research and technological capacities. They are becoming a natural space for innovation. The presence of universities, research centres, start-up incubators and cultural institutions creates a vibrant environment where ideas, talent and technology come together. Such an environment encourages experimentation, accelerates the development of new solutions and contributes to the formation of a dynamic and competitive economy.

Innovation-oriented cities are able to attract start-ups, investors and experts from various fields. High value-added job opportunities are created here, which exploit the potential of quality education while promoting diversity and international cooperation. A smart economy as per knowledge, digital technologies and creative industries thus becomes an engine of sustainable growth.

Smart Living is also in line with the principles of the New Urban Agenda (UN-Habitat, 2016, UN-Habitat, 2024, UN-Habitat, 2025), which emphasises the importance of inclusive, safe, resilient and sustainable urban development. The urban dimension optimises the physical space of the city through digital tools, sensor networks and data analytics. Smart lighting, adaptive transport systems, energy-efficient buildings and green infrastructure are examples of how technology is being integrated into everyday life. According to the European Smart Cities study (Giffinger et al., 2010), the link between technological innovation and the quality of public space is one of the key indicators of smart urban development.

One of the less discussed but fundamental aspects of Smart Living is the time sensitivity of the urban environment, also known as time ecology. This refers to a city's ability to respond to the rhythm of its residents' lives. It involves synchronising urban services, transport, lighting and cultural events with daily, weekly and seasonal cycles. In practice, this means, for example, flexible opening hours for public institutions, dynamic transport planning as per the actual movement of residents, and adaptive cultural programmes that respond to the current mood of the community. This approach, supported by research in the field of chrono-urbanism (Rojas-Rueda et al, 2024), enables cities to be not only smart but also responsive to their residents.

As Del-Real et al. (2023) point out, innovation for innovation's sake is

not smart. Only when a Smart City is connected to and responsive to its community can we say that the city is Smart. According to Wang and Zhou (2023), investment in ICT and human capital is a prerequisite for cities to effectively transform their systems into Smart Cities while improving the quality of life of their residents.

The concept of Smart Living is closely related to the issue of Quality of Life. Several authors (Smith et al., 2024, Shami et al., 2022) even use these terms interchangeably. Quality of Life is defined as a Smart City service that improves the standard of living (Lytras et al., 2021) using advanced integrated services as per information and communication (Helbing et al, 2021). The assessment of Quality of Life is as per indicators that can be used to assess how well people live in a given environment. The key indicators for assessment are service availability, health, safety, social relations, the environment and the subjective satisfaction of residents (Numbeo, 2025):

- ***Purchasing Power Index*** - this index expresses the ability of residents to purchase goods and services from their net income compared to local prices. Within the Smart Living concept, it is a key indicator of the economic affordability of life in a city, as it influences real access to the basic and developmental needs of residents (e.g. housing, education, healthcare and leisure activities).
- ***Safety Index*** - this index assesses the crime rate (e.g. the incidence of violent crime, theft, vandalism) and residents' subjective sense of safety. A safe environment is the basis for a high-quality and dignified life in the city, which is why Smart Living emphasises intelligent security systems that increase the protection of public spaces and reduce the risk of incidents (e.g. camera networks, lighting, sensors).
- ***Health Care Index*** - this index assesses the quality, accessibility

and effectiveness of healthcare services. Smart Living uses digital technologies that improve prevention, diagnosis and accessibility of care (e.g. eHealth, telemedicine, health sensors).

- ***Cost of Living Index*** - this index compares the prices of basic necessities with residents' incomes. Smart Living seeks to optimise costs through the efficient use of resources, thereby contributing to a more sustainable and affordable life (e.g. energy efficiency, smart housing, shared services). Reducing the financial burden on households through technological solutions leads to greater economic stability for residents, which reduces the risk of social exclusion and enables more equal access to basic services. At the same time, this index becomes an indicator of the effectiveness of public policies and the technological maturity of the environment.
- ***Property Price to Income Ratio*** - this indicator expresses the financial affordability of housing. By comparing the average price of real estate with the annual household income, it is possible to determine the real affordability of housing for the average resident. The Smart Living concept emphasises the development of affordable and energy-efficient housing solutions, such as smart buildings, modular housing and community forms of housing (e.g. co-housing), thereby reducing pressure on household budgets, improving housing affordability for broader sections of the population and promoting social stability in the urban environment. This approach also allows cities to respond flexibly to demographic changes, urbanisation growth and changing lifestyles, while housing remains economically sustainable and functionally adapted to the needs of residents.
- ***Traffic Commute Time Index*** - this index expresses the average

time residents spend commuting. Smart Living promotes intelligent transport systems, shared mobility, cycling and route optimisation using data, thereby reducing commuting time, reducing stress and improving work-life balance. This index is a key indicator of the effectiveness of urban planning and the quality of everyday life.

- ***Pollution Index*** - the index assesses the level of air, water and noise pollution and overall environmental quality. Smart Living focuses on green innovations that contribute to a healthier and more sustainable urban environment (e.g. air quality sensors, green roofs, smart waste management). This index is an indicator of environmental quality and a strategic planning tool for smart and healthy cities.
- ***Climate Index*** - the index assesses climate comfort in terms of temperature, humidity and seasonal fluctuations. Although the climate cannot be directly influenced, Smart Living promotes the adaptation of cities to climate change through green infrastructure, energy efficiency and resilience to extreme events, thereby increasing overall well-being.

Together, these indices provide a comprehensive picture of the living conditions and overall well-being of individuals in a particular city or region.

Numbeo's analysis of the quality-of-life index in selected countries for the period 2020-2025 reveals significant differences between regions, stabilisation trends after the pandemic and structural problems in some countries. The data indicate consistent development, but the dynamics of growth and decline vary according to the economic and political situation of the countries (see Figure 4.10). The results point to the fact that Western and Northern Europe are showing growth, while South-Eastern Europe is stagnating or declining. The leaders in growth are Luxembourg, Malta,

Sweden, Iceland and the Netherlands. Conversely, Serbia, North Macedonia, Bosnia and Herzegovina, Belarus and Hungary have experienced a decline: this result is likely to be related to the political and economic instability of these countries.

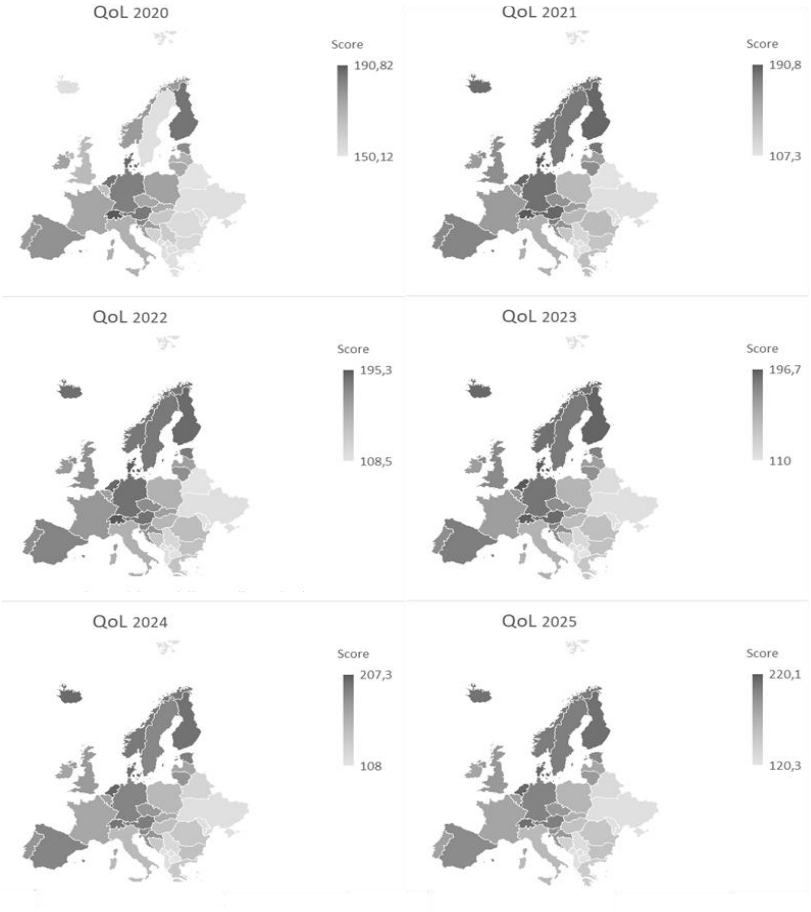



Figure 4.10

Quality of Life in European Country

Source: own processing as per Numbeo (2025)

Therefore, we include the following attributes among those of Smart Living (Vinod Kumar et al., 2020):

- A Smart City has strong and shared values.
- A Smart City records and celebrates local history, culture, and nature.
- A Smart City has a vibrant downtown, 24 h and 7 days a week.
- A Smart City can provide the necessary safety and security to women, children, and senior citizens.
- A Smart City improves the urban way of life.
- A Smart City builds natural and cultural assets to build a good quality of life.
- A Smart City not only understands the big picture of urban liveability but also pays attention to small details.
- A Smart City has high-quality open and accessible public spaces.
- A Smart City has high-quality public services and amenities.
- A Smart City is an ideal place of living, especially for women, children, and senior citizens.
- A Smart City organizes festivals that celebrate people, life, and nature in the city.
- A Smart City has a ritual event (or more) that symbolizes the values and aspirations of the community.

## 4.2 Examples in the field of Smart Living

Modern cities are increasingly concerned with improving the quality of life of their residents. Smart Living as a dimension of Smart City development involves the use of digital tools to promote health, safety, comfort, and an inclusive lifestyle. The aim of this concept is to create an environment that is not only technologically advanced but also sensitive to

the needs of diverse population groups. By integrating smart solutions into everyday life, cities are becoming dynamic ecosystems where quality of life is defined not only by the availability of services, but also by the level of personal well-being, safety and social cohesion.

***Brno, Czech Republic – urban comfort à la Tugendhat 2.0***

The unique innovation platform used by the Moravian metropolis of Brno as part of its Smart Living concept is as per dynamism, inclusiveness and a focus on results. BVV Living Lab (see Figure 4.11) is not just about supporting technological development. Its goal is to create conditions for the emergence of solutions that have a real impact on the quality of life of residents. By linking research, practice and user experience, Brno is becoming an epicentre of urban innovation with international reach. It is unique in that it allows innovations to be tested directly in an urban environment. Technologies, products, services and processes are tested in real-life conditions. BVV Living Lab provides companies, start-ups, universities a

nd other actors (BVV, 2024) with a base for testing products before they are launched on the market, access to the latest technologies and trends, the opportunity for visibility and networking, feedback from users and links to university projects.

The BVV Living Lab platform is a means of testing elements and processes that have the potential to improve air quality, increase transport safety, optimise energy flows, streamline urban services and strengthen community ties (Hloušek, 2024). In addition to technical projects, it also engages in cultural and social experiments. The involvement of residents in the BVV Living Lab project is one of its most fundamental elements, distinguishing this platform from traditional research and technology centres.


Figure 4.11

Brno Living Lab

Source: BVV (2024)

As per the Quality of Life (see Figure 4.12) assessment (Numbeo, 2025), Brno made the most significant progress in terms of purchasing power in the period 2020–2025.

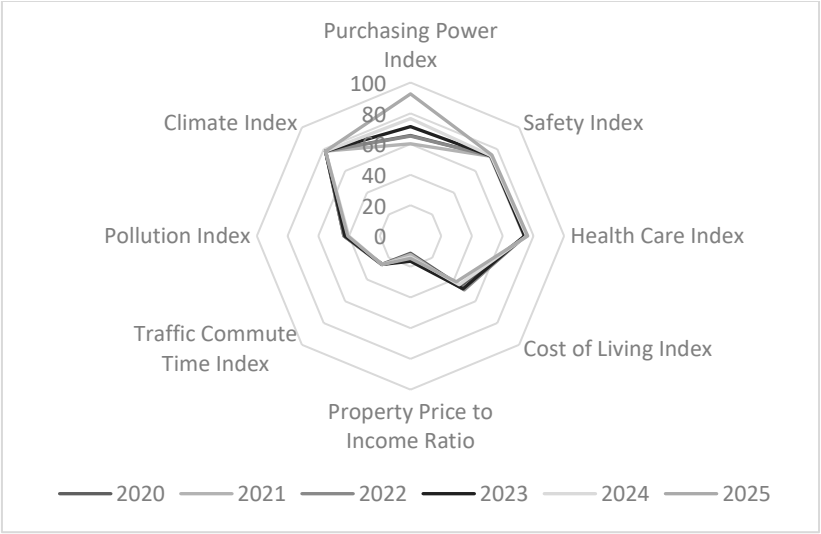



Figure 4.12

Brno - Quality of Life

Source: own processing as per Numbeo (2025)

***Hamburg, Germany – HafenLife experience***

One of the most comprehensive examples of a functioning Smart Living concept in Europe is the mySMARTLife project in Hamburg. The activities of the mySMARTLife project are divided into four themes: energy and infrastructure, mobility, digital communication and interaction with citizens. These main areas of work demonstrate how it is possible to achieve a system transformation that improves the quality of life of residents while reducing the environmental burden (Konsalt, 2024).

Energy efficiency is key to mySMARTLife. Both new and renovated buildings are equipped with smart technologies. This makes it possible to optimise energy consumption and use renewable sources. These sources include solar and geothermal energy in particular. In addition, local energy networks have been built (European Commission, 2025c). The added value of these networks is that energy production and consumption take place directly on site, reducing energy transmission losses and increasing energy self-sufficiency.

In the area of mobility, mobility hubs have been introduced. These are multimodal transport hubs that connect public transport, shared e-cars, bicycles and electric scooters (mySMARTLife, 2025, Hamburg, 2025). The city is thus promoting the transition to zero-emission transport. In the area of services, the city has started testing autonomous vehicles (See Figure 4.13), which aim to reduce traffic congestion and streamline logistics, for example in the area of parcel delivery, passenger transport, etc.

The digital infrastructure, Urban Platform (Urban Data Platform, 2024), collects, connects and processes data from various areas. This data is used to optimise urban services, streamline operations and improve decision-making. One example is adaptive lighting, which adjusts to the movement of pedestrians and cyclists, saving energy and increasing safety.

The participation of residents is also an integral part of the project. Thecity organises discussions, workshops and surveys to obtain feedback and enable citizens to actively participate in the development of solutions.


Figure 4.13
Smart Living - autonomous public transport
Source: Hamburg (2025)

Hamburg's Quality of Life (Numbeo, 2025) between 2020 and 2025 shows significant differences between the individual assessment indicators (see Figure 4.14). The most dominant trend is a sharp increase in purchasing power. In 2025, it reaches its highest values for the period under review, signalling the city's strong economic position and the growing availability of goods and services. Safety and healthcare have remained stable with a slight improvement, indicating consistent quality of public services. The cost of living has been on a slight downward trend. The standard of living has become more affordable, although the ratio of property prices to income and commuting times have remained virtually unchanged. Pollution has

decreased slightly, which is a positive sign for the environment, while climatic conditions have remained constant. Overall, Hamburg shows a clear shift towards economic prosperity while maintaining stability in other areas.

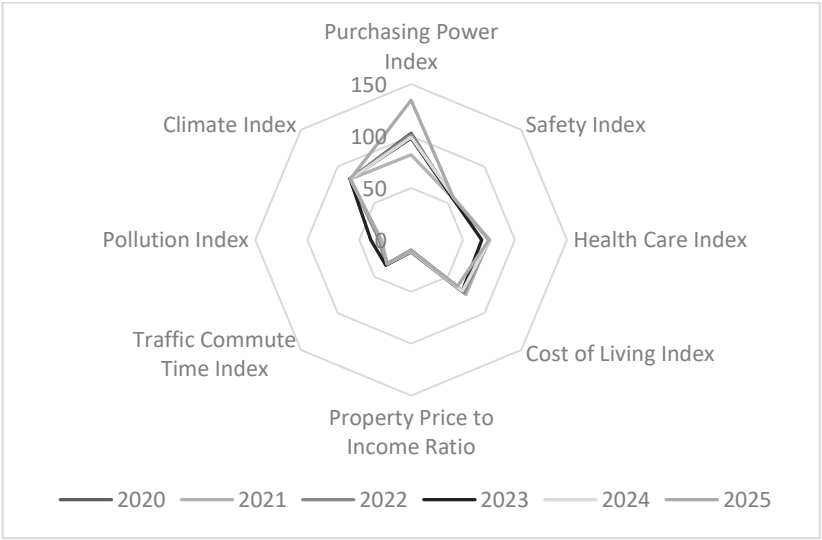



Figure 4.14

Hamburg - Quality of Life

Source: own processing as per Numbeo (2025)

## 4.3 Summary

A modern city is no longer just a collection of buildings, roads and networks. It is a sophisticated ecosystem of relationships where infrastructure meets emotions, data meets trust, and algorithms meet community. A new type of intelligence, known as urban intelligence, is forming in this space. This intelligence does not arise solely from technological innovations, but from the interaction between people, technologies, policies and cultural practices.

Cities are becoming living laboratories where meaningful ideas are tested. They are examples of good practice in terms of efficiency, social justice, environmental sustainability and cultural cooperation. Concepts such as time ecology and the Quadruple Helix model of cooperation show that Smart Living is not a technocratic project. On the contrary, Smart Living calls for the interconnection of academia, business, public administration and civil society.

Within the Smart Living model, technology does not take precedence over people. Digital tools, sensor networks, energy-efficient buildings, adaptive transport systems and inclusive public spaces are becoming the pillars of modern coexistence between the city's subjects and objects. Smart Living thus redefines urban space as an environment for a dignified, healthy and meaningful life. Thanks to this concept, quality of life is assessed not only by the availability of services, but also by the degree of personal well-being, safety and social cohesion.

Smart Living is a philosophy of urban life that emphasises shared responsibility. It is a path to cities that are not only smart, but also empathetic, inclusive and capable of co-creation.

# CHAPTER 5. SMART MOBILITY AND TRANSPORT - SUSTAINABLE MOBILITY IN THE DIGITAL AGE

The Smart Cities concept concerning the transport and mobility sector is predicated on an integrated approach to the functioning of urban areas, which has ramifications for various spheres of society, including culture, infrastructure, the environment, energy, and social services, among others. In each of these areas, several interrelated objectives are established, which collectively form a system grounded in the principles of sustainable social and economic development within the transport and mobility sector. The implementation of this system is a collaborative effort among public administration, the private sector, and civil society. The absence of any one of these components would render the achievement of the system's objectives unfeasible. This is due to the absence of an internationally binding legal definition or uniform legal framework that would precisely determine how to achieve the desired state. Each nation implements its own "smart" strategies and methodologies, which are aligned with global guidelines in this domain.

This chapter will address the issue of Smart City concepts analysis within the most important areas of policy relating to transport and mobility. A theoretical overview of each policy will be analyzed using a general overview analysis, approaches to solving the given policy, and success stories analysis and best practices overview in the EU and Slovakia and their comparison. Additionally, a draft of possible opportunities, recommendations, and suggestions for improvement will be provided, as well as an analysis of issues, challenges, benefits, problematic aspects in the EU and Slovakia in individual segments in Smart City policy concepts within transport and mobility.

## 5.1 Smart Transport and Mobility City policy concept

Mobility and transportation have been identified as pivotal factors influencing the socio-economic quality of life in urban centers. The implementation of intelligent transport systems and innovations in mobility has the potential to bring about significant improvements in the daily lives of residents, as well as in the broader economic and environmental context. Smart City policies in the domain of mobility and transport assume paramount importance in addressing the challenges associated with mounting traffic congestion, greenhouse gas emissions, and overloaded transport systems. The rapid process of urbanization that has occurred in recent decades has resulted in a series of challenges and changes in the domain of effective urban management. Urban areas are confronted with the imperative for sustainable and efficient solutions that guarantee a high quality of life for their residents, ranging from traffic congestion to environmental degradation. In response to these challenges and changes, the concept of the "*Smart City*" has emerged. Smart City is a transformational framework that utilizes technology and innovation to address the complex challenges posed by contemporary urban life. Mobility and transportation represent a pivotal facet of the Smart City Transportation paradigm. The efficient and sustainable operation of mobility systems is imperative for the effective functioning of urban environments, exerting a direct influence on economic productivity, social inclusion, and environmental health. The integration of innovative technologies, including Intelligent Transportation Systems (ITS), electric and shared mobility, and data-driven urban planning, presents an unprecedented opportunity to transform urban transportation networks. This subchapter analyzes the elements of the Smart City policy concept in the field of mobility and transport, with a particular emphasis on their impact on socio-economic quality of life. The primary objective of this initiative is to investigate

the potential of smart mobility solutions to address urban challenges, including traffic congestion, pollution, and accessibility, while concurrently augmenting economic opportunities and enhancing social justice. The subchapter will demonstrate how the implementation of Smart City principles in the domain of mobility can serve as a catalyst for socio-economic development, thereby promoting more livable, sustainable, and inclusive urban spaces. By addressing the critical interaction between technology, policy, and quality of life, the subchapter contributes to the ongoing discourse on sustainable urban development and offers practical recommendations for urban planners and other practical applications. Specifically, within the theoretical framework of Smart City Mobility in the field of transport, aspects such as smart mobility and intelligent transport, the principle of MaaS (Mobility as a Service), Intelligent Transport Systems (ITS), Electric and Shared Mobility, and the aspect of public transport digitization will be analyzed. Subsequently, specific approaches, examples, and best practices for implementing Smart City Mobility in cities in the EU and Slovakia will be presented and evaluated as part of an analysis of benefits and limitations, as well as proposals for improving the use of Smart City policy in the field of mobility and transport.

## 5.2 Smart transportation and Smart City mobility concept - general overview analysis

Smart mobility and intelligent transport represent contemporary approaches to addressing urban mobility and transportation challenges. These concepts leverage technological advancements and innovative solutions to enhance efficiency, improve user comfort, and mitigate the environmental impact of transport systems. Smart mobility is an emerging concept that emphasizes multimodal transportation, which integrates various modes of

transportation (e.g., public transit, bicycles, and car sharing) into a cohesive system. Intelligent transport, a subset of smart mobility, encompasses specific solutions and technologies designed to enhance transport systems (Pisoni et al., 2022; MIRRI, 2022). Smart mobility and intelligent transport are instrumental in the development of modern cities and enhancement of the quality of life for their inhabitants. However, the successful implementation of these measures necessitates strategic planning, cross-sector cooperation, and support for sustainability. These innovative approaches are imperative for addressing current transport challenges and ensuring the long-term prosperity of urban regions. Transport innovations have emerged as a pivotal solution to address pressing challenges, including road congestion, air pollution, and the imperative for sustainable mobility. Among the most significant approaches are autonomous vehicles, shared transportation, and public transportation using the Internet of Things (IoT). These technologies contribute to more efficient, environmentally friendly, and comfortable transport. Autonomous vehicles are equipped with sophisticated sensors, artificial intelligence (AI), and data processing systems that facilitate operation independent of operator intervention. The primary advantages of autonomous vehicles are twofold: first, they contribute to an enhancement in the overall safety of the nation's roadways; and second, they play a pivotal role in the reduction of vehicular accidents that are attributable to human error. Additionally, autonomous vehicles facilitate a more efficient utilization of the nation's road infrastructure (Ren et al., 2020). Research indicates that the implementation of autonomous technologies has the potential to reduce fuel consumption and CO2 emissions by up to 20%, through the optimization of routes and the mitigation of traffic congestion. Conversely, the integration of autonomous vehicles into the prevailing transportation network, along with pertinent legislative concerns and public

acceptance, persist as substantial challenges (Nikitas et al., 2021). Other innovations in transport include shared transport, which involves mobility models where multiple users share the same means of transport, such as cars, bicycles, or electric scooters. This concept has the potential to reduce the number of private vehicles on the road, thereby reducing infrastructure congestion and greenhouse gas emissions. The implementation of IoT technologies in public transportation facilitates the collection of real-time data, its subsequent processing, and analysis, thereby enhancing operational efficiency and enhancing the user experience. The integration of IoT devices, including sensors, GPS locators, and smart stops, has been demonstrated to enhance communication between transport operators and passengers. The judicious administration of public transportation, the integration of diverse transportation modes, and the enhancement of the availability and quality of urban transportation services have been identified as pivotal factors in ameliorating the traffic situation in the city and curtailing emissions. By leveraging data from sensors, security cameras, and internet connections, the city can effectively monitor traffic conditions, disseminate data analysis outputs on municipal applications, and dynamically adjust traffic settings or parking strategies in real time according to prevailing circumstances. A comprehensive strategic approach to promoting "smart mobility" in the future must include support for a combination of multiple modes of public and private transportation, as well as the introduction of new forms of transportation, such as electric vehicles, hydrogen-powered vehicles, autonomous vehicles, bike sharing, and carpooling/car sharing (Shaheen, et al., 2020; Hassan M. A., et al. 2023).

The objective of the smart mobility concept is to enhance, interconnect, and achieve a more environmentally friendly, secure, and efficient transport system in urban areas. This phenomenon is primarily facilitated by various

forms of public transportation, including trams, trolleybuses, subways, and cycle paths, which are being constructed in major metropolitan areas along designated transport routes. However, it is important to note that car sharing, and smart scooter stands can also be included in this concept (see Figure 5.15; Bárta, 2016; Alam et al., 2024).

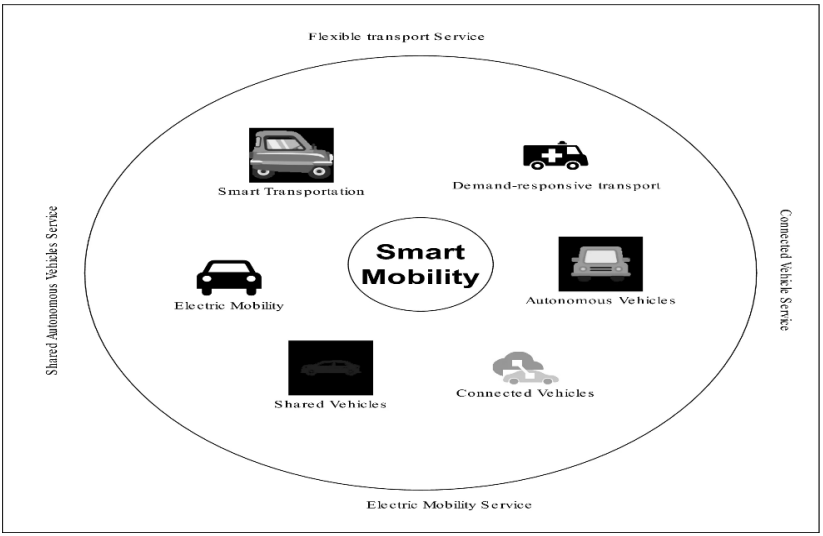



Figure 5.15

Smart Mobility

Source: Alam, et al. (2024)

Smart mobility comprises a range of solutions. These objectives encompass, but are not limited to, the enhancement of transportation networks and traffic management systems, the expansion of public transportation, the facilitation of parking, the attainment of enhanced safety measures, the reduction of traffic accidents, the augmentation of transport efficiency, the mitigation of emissions, and the reduction of carbon

footprints. The primary objectives of the smart mobility initiative are as follows (Lewis, 2019):

- Sustainable, innovative, and safe transport systems.
- Access to different modes of transport.
- Good transport accessibility throughout the city.
- Integration of non-motorized transport.
- Integration of information and communication technologies into transport systems.

To address these challenges, cities must prioritize the development of *MaaS (Mobility as a Service)* services as a strategic solution. MaaS is a purely digital platform that aims to provide mobility services as an alternative to transport by private motor vehicle. The MaaS digital platform enables passengers to personalize their mobility needs, integrating shared resources from origin to destination. This flexibility caters to various factors, including weather and health conditions, ensuring a customized and efficient journey for all users. Following the configuration of their transport chain within the MaaS environment, passengers have the option to utilize cashless payment via smartphone to cover the costs of these services in advance. This approach eliminates the need for additional fees during their journey, thereby facilitating a seamless and hassle-free travel experience. The utilization of MaaS services for urban travel is advantageous for the following reasons (Alam et al., 2024; Gassmann et al., 2019; Narayanan & Antoniou, 2023):

1. Travelers have identified numerous advantages associated with opting for alternative transportation modes in lieu of private vehicles. These benefits encompass a reduction in travel expenditures, the cultivation of communal cohesion, and the establishment of a sense of social responsibility concerning the resolution of urban transportation challenges.

2. Transport operators have been shown to contribute to job growth in the transport services sector by providing shared mobility options. Furthermore, they have been demonstrated to promote the sustainability of urban transport by developing the provision of alternative transport services.
3. Urban planners will be able to improve their interventions in urban planning and develop more effective models for urban development as per data from the field of urban transport.
4. City councils should recognize the potential of modern digital technologies in the domain of urban transportation to foster economic prosperity while concomitantly mitigating the adverse environmental impacts of transportation.

Integrated mobility systems, such as MaaS, have the potential to streamline access to various transportation modes, thereby mitigating barriers associated with the digital divide. Intuitive platforms have the potential to facilitate the planning of journeys and the payment for services, thereby enhancing users' mobility and promoting the utilization of environmentally friendly transportation modes. The provision of incentives for electric vehicles, such as tax reductions or financing for charging infrastructure, is a strategy that has the potential to encourage their adoption and accelerate the transition to sustainable mobility. The integration of effective information and incentives for travelers has been demonstrated to have a substantial impact on enhancing the efficiency of transportation systems, promoting environmental sustainability, and enhancing safety (Butler et al., 2020).

*Intelligent transport systems (ITS)* facilitate real-time monitoring, traffic flow management, and information provision, thereby enhancing the decision-making processes of users and policymakers. Investments in ITS have been demonstrated to augment the potential for future innovation and to

fortify the capacity of systems to address contemporary transport challenges. Intelligent transport systems leverage modern technologies to manage and optimize transport, resulting in numerous socio-economic benefits:

- *Improved access to job opportunities*: Efficient and reliable transportation increases the availability of jobs to a wider population, which can contribute to reducing unemployment and increasing economic activity.
- *Promoting economic growth*: The development of transport corridors and infrastructure can stimulate economic growth in adjacent areas by improving access to markets and resources.
- *Reduction of emissions*: Optimizing transport and promoting environmentally friendly modes of transport, such as electric cars and public transport, leads to a reduction in greenhouse gas emissions and air pollution.
- *Improved air quality*: Less congested roads and smoother traffic contribute to a reduction in the concentration of harmful substances in the air, which has a positive impact on the health of the population (Alam, et al. 2024a).

Intelligent transport systems (ITS) are defined as the integration of modern information and communication technologies into transport infrastructure and vehicles. The objective of ITS is to enhance the safety, efficiency, and sustainability of transport. *The primary components of ITS* include traffic management, intelligent traffic lights, and traffic monitoring. *Traffic management* constitutes a pivotal component of intelligent transport systems. Contemporary traffic management systems employ dynamic procedures to avert disruptions in traffic flow, thereby enhancing the smoothness and safety of road traffic. The implementation of LED traffic lights furnishes road users with contemporary information regarding traffic

conditions, thereby facilitating optimal traffic flow. Strategic traffic management is a term used to describe the optimization of traffic flow movement within a road network. The objective of this management strategy is to improve the quality of transport services within a specified geographical area. Other types of intelligent transport systems include intelligent traffic lights. *Intelligent traffic lights* are equipped with sensors and algorithms that analyze current traffic conditions and adjust signal cycles in real time. This adaptive approach has been demonstrated to reduce waiting times for both drivers and pedestrians. For instance, adaptive traffic lights have the capacity to dynamically modify the duration of the green signal in accordance with traffic intensity, thereby facilitating more uniform vehicular movement and reducing emissions. *Real-time traffic monitoring* constitutes an integral component of intelligent transportation systems. The utilization of contemporary technologies, including cameras, sensors, and drones, facilitates the aggregation and examination of data concerning traffic intensity, vehicle velocity, and incident identification. This data is then used to inform drivers about current conditions, plan routes, and, for example, systems using artificial intelligence can automatically detect traffic jams, track stationary vehicles, and count the number of passing vehicles, contributing to more efficient traffic monitoring and management. The implementation of ITS has been demonstrated to engender a number of benefits, including increased safety, reduced traffic congestion, and enhanced overall efficiency of the transport system. Nevertheless, the matter of ensuring interoperability among disparate technologies and systems, in addition to the protection of privacy and security of collected data, remains unresolved (Government SR. 2008; Almutairi, 2023; Narayanan, Antoniou, 2023; Porru, et al. 2020).

The subsequent section will methodically *assess six identified smart*

*mobility innovations within intelligent transport systems (ITS)* according to sustainability assessment criteria, including safety, congestion, energy consumption, environmental impact, and accessibility (Lindkvist, Govik, 2024; Alanazi, 2023; Almutairi, 2023; Bıyık, et al. 2021).

***Safety***. Smart mobility innovations present significant opportunities to enhance the safety of the transportation system; however, they also carry certain risks. The primary advantages of intelligent transport systems include the capacity to facilitate accident monitoring, expeditious incident management, and enhanced vehicle and personal safety. The dissemination of real-time information has the potential to facilitate the efficient allocation of emergency services, such as police, ambulances, and firefighters, to the precise locations where they are required. Additionally, ITS facilitates the identification of drivers who are operating vehicles illegally, thereby mitigating the risks associated with their presence on the roadways. From the perspective of the vehicles themselves, the integration of assistance systems, such as voice activation and the automation of many tasks, has been demonstrated to minimize driver distraction and eliminate human error. Such measures have the potential to reduce accidents by up to 80-90% and generate significant economic benefits, including lower insurance costs and reduced road congestion. However, it is imperative to acknowledge that these technologies are not without their inherent risks. Privacy and information security are of paramount importance, as ITS systems frequently process personal data and are susceptible to cyberattacks, network failures, and data manipulation. These issues have the potential to act as deterrents for users, particularly in contexts that necessitate online payment systems or the dissemination of personal data. Autonomous vehicles (AVs) face an additional challenge in the need for rapid and ethical decision-making in critical situations, which requires clear ethical and regulatory guidelines. It is

imperative to acknowledge the inherent safety risks associated with shared environments, particularly in contexts involving pedestrians or the utilization of personal mobility devices (PMDs). Accidents and physical injuries are potential outcomes in these scenarios. Concurrently, there is considerable potential to enhance safety in areas with inadequate public transportation or elevated crime rates. This can be achieved through the utilization of shared mobility services or door-to-door transportation options. In order to address these challenges, it is imperative to implement reliable and secure technological solutions that emphasize data anonymization and privacy protection.

***Congestion***. Smart mobility innovations present opportunities to address congestion issues, particularly through enhanced traffic management, such as redirecting traffic to uncongested routes, prioritizing public transportation, and optimizing traffic signal timings. These innovations also support shared mobility, which can reduce the number of vehicles per passenger. Operational improvements, such as driver assistance systems, driving automation, and the use of autonomous drones for passenger transport, are also discussed. Conversely, these innovations concomitantly engender risks. The implementation of shared mobility services may necessitate additional space for loading and unloading operations, which can result in a reduction in available road capacity. This, in turn, may encourage a transition away from high-capacity public transportation options, thereby leading to an increase in the total number of kilometers traveled. The introduction of autonomous vehicles (AVs) has the potential to exacerbate congestion on transportation networks. This is due to the fact that AVs would grant access to transportation to new groups of users, result in extended travel distances due to the increased value of time, and lead to an increase in so-called "blind rides"—trips without passengers.

***Energy consumption***. Achieving environmental sustainability necessitates the improvement of energy consumption in mobility. The implementation of intelligent traffic management systems has been demonstrated to facilitate more efficient traffic flow, thereby reducing the frequency with which vehicles must brake and accelerate, and consequently, decreasing fuel consumption. The integration of automated vehicles (AVs) has the potential to reduce energy consumption by up to 45%. However, the increased vehicle kilometers traveled (VKT), including unmanned driving, can lead to an increase in consumption by up to 300% if these technologies are not implemented effectively. In order to mitigate the aforementioned negative impacts, the implementation of shared fleets and ride optimization systems is imperative to enable efficient vehicle utilization and minimize energy losses. A pivotal solution for sustainable mobility is the transition to alternative fuels, particularly battery electric vehicles (BEVs), which are more energy-efficient than combustion engines, even with carbon-intensive electricity grids. The implementation of decentralized solar charging stations has the potential to alleviate the burden on the electricity grid while promoting the availability of green solutions in less developed regions. To ensure the successful implementation of these innovations, public awareness campaigns are essential to increase the acceptance of green technologies and support the transition to sustainable forms of transport. The confluence of technological and cultural shifts presents a substantial opportunity to curtail emissions and energy consumption while preserving the efficacy of transport systems.

***The environmental impact***. Smart mobility innovations have the potential to exert a considerable influence on the environment, with their effects frequently being interconnected. Increased congestion has the potential to result in higher energy consumption and greater emissions.

Concurrently, heightened demand for road space and infrastructure can exert increased pressure on land use for transport purposes. Conversely, advancements in vehicle energy efficiency and the promotion of sustainable transport, such as battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), have the potential to curtail greenhouse gas emissions and enhance air quality. This is of particular significance in developing countries, where transport is responsible for up to 80% of emissions. The integration of shared mobility and smart parking systems (SAPS) has been demonstrated to effectively reduce parking demand by up to 90%, thereby liberating urban space for alternative uses, such as the development of parks, cycling infrastructure, and community activities. The implementation of more efficient IDS systems will also facilitate enhanced parking management, thereby reducing mileage and associated emissions. However, the implementation of smart mobility strategies necessitates substantial investments in ICT infrastructure and charging stations, which concomitantly impose an environmental burden associated with their construction and operation. The advent of long-distance travel facilitated by advanced vehicle technologies (AVs) has the potential to precipitate suburbanization, thereby exacerbating the existing burden on land and infrastructure. In order to mitigate these impacts, the implementation of policies that prioritize efficient land use and the development of transit-oriented areas is essential. Concurrently, it is imperative to capitalize on the diminished demand for conventional infrastructure, such as gas stations and parking lots, to foster more sustainable and environmentally friendly urban environments.

***Accessibility***. MaaS (Mobility as a Service) and AVs present novel opportunities for individuals with reduced mobility, enhancing access to employment and services. The implementation of shared mobility and integrated systems has the potential to substantially alleviate the economic

burden on individuals. Nevertheless, the digital divide and the substantial initial costs can impede equitable access and exacerbate social divisions. Consequently, the formulation of mobility policy should prioritize the assurance of equitable access, with measures such as subsidies or the implementation of programs aimed at promoting digital literacy. Smart urban mobility signifies a pivotal transformation in the domains of transport and urbanism. The efficacy of this paradigm hinges upon the successful integration of technological innovation with regulatory frameworks, environmental sustainability, and social inclusion. Achieving an optimal balance between efficiency and equity is imperative for ensuring the long-term sustainable development of urban areas and enhancing the quality of life for their inhabitants. The processes of urbanization and suburbanization have led to a marked increase in the population of certain urban regions, resulting in increased population density and mobility. Consequently, a conceptual framework is required to address issues such as traffic congestion, public transportation, information and communication systems, and non-motorized vehicles. As previously mentioned, smart mobility is a concept for urban development as part of a Smart City as per information and communication technologies. The provision of transport services is predicated on the principles of accessibility, safety, convenience, speed, and affordability for the community (Butler et al., 2020).

***Shared mobility*** is a critical component of efficient resource utilization. The implementation of car, bicycle, and scooter sharing systems has been demonstrated to reduce private vehicle ownership and promote public transportation, particularly in densely populated areas. The integration of these systems with electric vehicles has the potential to enhance network capacity and reduce environmental impacts. In the context of sustainable development, the prioritization of shared autonomous vehicles (SAVs)

emerges as a pivotal strategy. These vehicles have been shown to exhibit superior resource efficiency, thereby positioning them as integral components within comprehensive mobility services, such as MaaS (Mobility as a Service). The promotion of remote working, transit-oriented development, and active mobility (i.e., walking and cycling) has the potential to contribute to a significant reduction in road congestion, individual transportation costs, and environmental impacts. The shared mobility system encompasses a variety of transportation services in which vehicles are shared either at different times (e.g., bike sharing, car sharing, scooters) or between multiple passengers during a single journey (e.g., carpooling, ridesourcing). This notion is not a recent development; conventional methods such as taxis, public transportation, and car and bicycle rental services have existed for decades. In large cities, bicycle-sharing programs and scooter services are being utilized as first- and last-mile solutions, thereby enhancing access to public transportation and reducing the number of private vehicles. The transition to shared mobility is pivotal to the advancement of smart mobility and the development of more sustainable cities. This transition offers numerous advantages, including a reduction in car ownership, a decrease in vehicle kilometers traveled (VKT), and a positive impact on the environment, society, and the economy. Concurrently, it enhances the quality of life by reducing travel time and enabling more leisure time for family activities. In order to facilitate job accessibility, it is imperative to employ a strategic approach in the location of commercial and industrial zones in close proximity to major transportation hubs. The implementation of such solutions has been demonstrated to have a dual impact: on the one hand, they contribute to the promotion of economic growth; on the other hand, they improve social justice by reducing barriers to job access. Another concept to consider is car-sharing. The sharing economy is predicated on this principle.

The pivotal factor in this paradigm shift is the transition from a ownership-based model to a new approach that emphasizes consumer participation in the sharing of access to entities and individual components. The fundamental distinction is that consumers no longer have to possess physical assets, as they can access them through rental arrangements that are economically viable. The mobility sector, which is characterized by the provision of shared or communal resources, has emerged as one of the most rapidly expanding segments within the broader sharing economy. The practice of car sharing has emerged as a prominent innovation within the broader context of sustainability in the transport sector. The operational mechanism is straightforward: consumers rent a vehicle for a specified duration at an established rate. At the conclusion of the rental period, the user simply relinquishes control of the vehicle at the location specified by the application, thereby enabling another individual to commence utilization of the vehicle. This approach effectively mitigates the challenges associated with car ownership, as evidenced by previous studies (Song et al., 2017).

***The digitization of public transportation*** entails the incorporation of contemporary digital technologies into existing transportation systems with the objective of enhancing efficiency, accessibility, and sustainability. This transformation encompasses the implementation of intelligent solutions that enhance the planning, management, and utilization of transport services. An initiative aimed at the digitization of public passenger transportation was implemented in the Banská Bystrica region of Slovakia. The objective of this initiative was to establish an integrated transportation system that would employ digital tools to enhance coordination among various modes of transportation and augment passenger comfort. This initiative encompassed the implementation of a unified ticketing system, the provision of real-time information regarding departures and arrivals, and the

development of mobile applications designed for trip planning. At the European level, a report on the digitization of European industry was adopted, emphasizing the importance of digitization in the transport sector. The advent of digitization has engendered a plethora of novel opportunities for manufacturers, operators, investors, workers, and passengers. Moreover, it has emerged as a prerequisite for enhancing the competitiveness, sustainability, and quality of public transport services. The integration of digital technologies within public transportation systems introduces a range of challenges, including the imperative to ensure cybersecurity, the protection of personal data, and the interoperability among disparate systems. Notwithstanding the aforementioned challenges, the process of digitization is a critical component in the modernization of public transportation and the enhancement of citizens' quality of life (European Parliament, 2017; Chahbani et al., 2022).

## 5.3 Smart City mobility policy success stories analysis and best practices overview in EU and Slovakia

This chapter presents the results of an analysis of the elements of the Smart City policy concept in the field of mobility and transport and their impact on improving the socio-economic quality of life. The analysis encompasses case studies of successful implementations from various cities worldwide, with a focus on the identified benefits, challenges, and key success factors. The primary objective of this chapter is to provide an empirical perspective on the efficacy of Smart City solutions in the domain of mobility. The emphasis is placed on identifying specific benefits, such as improved transport accessibility, increased environmental sustainability, reduced traffic congestion, and increased resident satisfaction. The ensuing sections will present particular findings, along with an interpretation of their

significance in the context of the socio-economic benefits and challenges associated with Smart City policy in the domain of mobility and transport. This will be achieved within the framework of an overview of the current state of specific Smart City policies in the domain of transport and the response to intelligent transport systems in cities and municipalities in Slovakia and the EU. Furthermore, the processes of implementation of local Smart City mobility in Slovak and European cities will be examined, including successful projects and practical examples.

### 5.3.1 Analysis of successful implementations of smart mobility and intelligent transport in the EU

The European Union considers transportation to be one of the fundamental pillars of the single market. The presence of adequate transportation infrastructure is imperative for the promotion of economic growth and the enhancement of the quality of life experienced by citizens. While the primary responsibility for this initiative lies with Member States, the EU has demonstrated a commitment to promoting sustainable urban mobility by offering a range of instruments to support this objective. The principle of subsidiarity ensures that the EU intervenes only when it is necessary. The European Union is currently experiencing a significant degree of urbanization. By the year 2050, the European Commission anticipates that urbanization will reach 80%, with certain countries, including Belgium, the Netherlands, Sweden, and Luxembourg, potentially surpassing 90% (European Commission, 2017). The European Union has been addressing the issue of sustainable mobility in cities since the 1980s. The European Union acknowledges the significance of sustainable urban mobility and has, as such, allocated substantial financial resources under the Horizon 2020 program to support innovative projects in this domain. The objective of this initiative is

to promote the more efficient use of resources, to reduce traffic congestion and accidents, and to stimulate the development of the transport industry. The European Union has expressed a strong commitment to the promotion of sustainable urban mobility. A substantial financial allocation is available from European funds, amounting to billions of euros, to municipalities for initiatives that promote the enhancement of air quality and the reduction of reliance on automobile transportation. In addition to financial support, the EU also provides technical assistance to cities in the preparation and implementation of these projects. The European Union has expressed a strong commitment to the promotion of sustainable urban mobility. A substantial financial allocation is available from European funds, amounting to billions of euros, to municipalities for initiatives that promote the enhancement of air quality and the reduction of reliance on automobile transportation. In addition to financial support, the EU also provides technical assistance to cities in the preparation and implementation of these projects. In order to support the development of Smart Cities, the European Commission has established an initiative under the title of the European Innovation Partnership on Smart Cities (European Commission, 2017; European Commission, 2025). The following examples can be mentioned in the analysis of successful implementations of Smart City mobility and intelligent transport around the world and in EU countries.

*Copenhagen, Denmark*: Smart cycling infrastructure. Copenhagen, known for its emphasis on cycling, has implemented smart cycling infrastructure that includes:

- Smart traffic lights: which give priority to cyclists and reduce their waiting times.
- Traffic sensors: which collect data on the use of cycle paths and assist in planning their expansion.

- Cycling counters: which motivate residents to use bicycles more.

Benefits:

- Reduction of the city's carbon footprint.
- Increase in the share of bicycle transport to 41% of total transport.
- Improvement in residents' health.

Challenges:

- The need to integrate bicycle transport with other modes of transport (Airey, Grenfell, 2016).

*Singapore:* Intelligent traffic management. Singapore is a leader in the field of intelligent transport. Elements of their system include:

- ERP system (Electronic Road Pricing): Dynamic road usage charges as per current traffic.
- Traffic prediction system: Use of artificial intelligence to predict traffic jams and optimize traffic flows.
- Integration of public transport and shared mobility: IoT systems and trip planning applications.

Benefits:

- 30% reduction in traffic congestion.
- Increased public transport efficiency.
- Better real-time traffic monitoring and management.

Challenges:

- High implementation costs.
- Protection of passengers' personal data (Docherty, Marsden, Anable, 2018).

*Barcelona:* Barcelona - Smart City solutions. Barcelona is considered one of the best European cities in the field of Smart City. As part of its Smart City program, Barcelona has implemented several innovations, such as smart parking systems, smart streetlights, and data collection systems to improve

urban planning. These technologies have contributed to reducing energy consumption, improving mobility, and increasing the quality of life for citizens. The city is also a leader in data management, having created an open platform for data sharing between different sectors and businesses.

Digitization of public transport. Barcelona has implemented integrated digital solutions in its public transport system:

- Smart bus stops: providing real-time information on service arrivals.
- Mobile apps for passengers: enabling route planning and ticket purchasing.
- Emissions monitoring: IoT sensors track the environmental impact of transport.

Benefits:

- Increased passenger satisfaction.
- Better coordination between different modes of transport.
- Reduced $CO_2$ emissions.

Challenges:

- Need to modernize older infrastructure (Lurkin, et al. 2018).

In *Austria*, a pilot project is underway to address the issue of graffiti on trains. This initiative, originating from Slovakia, exemplifies a cross-border collaboration that transcends geographical boundaries. The system is designed to function through the use of microphones placed in carriages, which are tasked with the recording of events in the surrounding area. The utilization of artificial intelligence algorithms will empower them to discern the auditory characteristics of spray cans and paint being applied. In the event that the system detects any suspicious sounds, it is programmed to initiate appropriate action, such as notifying the appropriate law enforcement authorities.

*Amsterdam* has been a proponent of ecological and intelligent solutions.

Amsterdam serves as a notable illustration of a European city that has effectively implemented Smart City solutions. The municipality has implemented solutions that are as per renewable energy sources, intelligent traffic management, and carbon footprint reduction. A notable example is the Amsterdam Smart City project, which utilizes a shared data system to provide local businesses, local governments, and citizens with valuable information regarding air quality, energy consumption, and traffic flow. Amsterdam is a constituent element of the City Service Development Kit project. This platform enables the real-time recording and distribution of data, which is subsequently utilized by developers to create software applications that are of practical value. Examples of such uses include:

- creating services to improve transport,
- simplifying the reporting of problems that arise in the city at any given moment,
- enabling the monitoring of air pollution, noise, and light intensity,
- introducing the Mobypark app, through which Amsterdam residents can offer their parking spaces for a fee (European Commission, 2025e; Cavada, 2017).

Amsterdam has initiated a noteworthy project in the domain of work, namely "smart working," which constitutes an alternative workspace where residents have the opportunity to work remotely and circumvent the need for commuting to the city center. The impetus for this project was the frequent congestion of the transportation network, which persisted even during off-peak hours (Amsterdam Smart City).

TraficLink is addressing the city's traffic congestion by creating a new transport system called the Digital Road Authority. This system provides real-time traffic density information. The application utilizes this data to guide its users along the most efficient route, as determined by Amsterdam

Smart City. The utilization of electric vehicles equipped with solar panels has been on the rise in urban centers. These services are primarily designed for residents who wish to navigate the city without the constraints imposed by parking restrictions, thereby facilitating more efficient travel. A notable benefit of electrifying urban transportation is the concomitant reduction in the number of vehicles and the resultant decrease in CO2 emissions (Amsterdam Smart City). Across Amsterdam, "living labs" have been established, serving as experimental platforms for evaluating novel technological inventions in their intended operational environment prior to their city-wide implementation.

Smart City in *the Czech Republic*. With regard to our neighbors, the Czech city of Kyjov is among the Czech cities with developed Smart City elements. The transition to Smart Cities commenced with the substitution of traditional street lamps with more cost-effective LED lamps. These LED lamps were equipped with controllers and sensors, enabling them to autonomously record and report malfunctions. Concurrently, technicians were able to remotely control the lamps via a mobile application, facilitating efficient maintenance and management of the lighting infrastructure. The city has announced its intention to install additional components on these poles, including temperature and air quality sensors, as well as cameras, with the objective of monitoring parking and municipal waste collection sites (European Commission, 2025h).

### 5.3.2 Examples of Smart City practices from Slovakia in the current situation and ways of responding to intelligent transport systems in cities and municipalities

The Slovak Republic is undertaking a gradual process of expanding the scope of digital public services and integrating them with the broader

array of services offered by the European Union. In 2018, the Slovak Republic endorsed European declarations that call for the enhancement of cross-border collaboration throughout Europe in the domain of artificial intelligence. The deficiencies in the transport network could be addressed by enhancing the connections within existing public and urban transportation systems, as well as by promoting sustainable transportation options. The implementation of smart solutions has been shown to engender new opportunities for the enhancement of autonomous management, more effective cooperation between ministries, and better connections between local governments and citizens.

This includes the procurement of personnel for the creation, evaluation, and implementation of smart solutions. It will also facilitate cooperation between cities, particularly within city districts, which necessitates effective collaboration among various local governments, both large and small (Kona, Guťan, Horváth, 2020). A significant component of this initiative is *Smart Mobility Slovakia*, which has assumed a pivotal role in the implementation of smart mobility solutions within the Slovak context. This principle was established as a formal representative of the smart mobility ecosystem with the objective of enhancing collaboration between key partners at the domestic and international levels.

The central communication point for these initiatives is the smartmobility.gov.sk portal, which serves to coordinate and support activities in the field of smart mobility. The Smart Mobility Slovakia platform was established through the initiative of the Ministry of Investment, Regional Development and Informatization of the Slovak Republic (MIRRI SR) as part of a national project focused on the development of smart mobility. This project, which was initiated in 2019 in collaboration with the Ministry of Transport and Construction of the Slovak Republic, seeks to establish

conducive environments for the proliferation of intelligent transportation solutions.

The primary mission of the association is to promote the advancement of smart mobility, which aims to provide effective, sustainable, and environmentally responsible transportation solutions. From the perspective of cities and municipalities in the Slovak Republic, the implementation of intelligent transport systems (ITS) reflects varying levels of technology adaptation across regions.

A recent study, titled "*Analysis of the Use of Intelligent Transport Systems in Cities and Municipalities of the Slovak Republic, 2023*," sought to ascertain the prevalence of Smart City concepts in Slovak municipalities. The study's findings, detailed in the accompanying document, revealed that only 58 cities and municipalities had adopted at least one Smart City concept solution, with Intelligent Transport Systems (ITS) playing a pivotal role in these initiatives. This information is further illustrated in Figure 5.16 of the document (MIRRI, 2021).

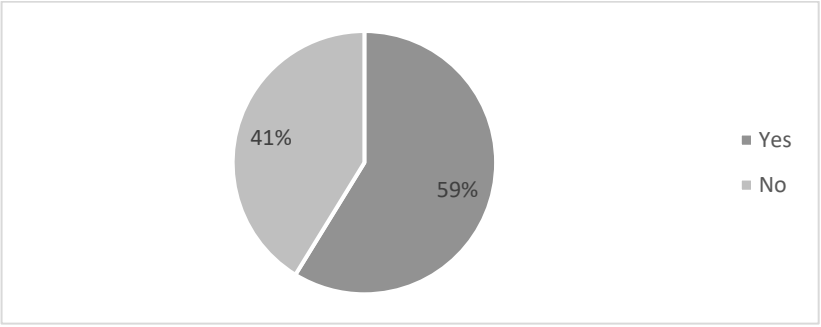



Figure 5.16

Implementation of solutions within SmartCity

Source: MIRRI (2021)

One such IDS is employed in *Trencin*, where an advanced parking space monitoring system has been implemented using sensors embedded in the asphalt. This system enables residents to ascertain the availability of parking spaces in real time through a mobile application and directs them to the nearest available spaces. Furthermore, the city has implemented a system of smart cameras that are capable of autonomously identifying potentially hazardous situations and disseminating notifications to the police force when deemed necessary.

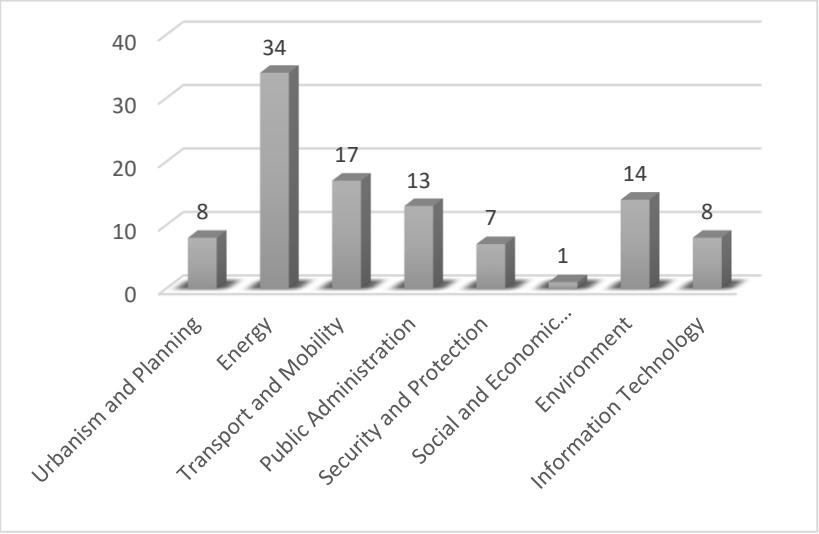



Figure 5.17

SmartCity Areas of expertise for implemented SmartCity solutions

Source: MIRRI (2021)

The sophisticated analytics of these camera systems can even identify litter in the frame and automatically alert the cleaning crew, thereby enhancing the efficiency of municipal services. A select number of parking

spaces are equipped with a built-in sensor that detects the presence of a vehicle in that specific space. This data is transmitted to a server via a specialized network that has been designed expressly for this application. Subsequently, users can access the ParkDosts mobile application, where they can view available parking spaces on a map.

The app provides users with the ability to view parking costs for each zone and to purchase or extend parking tickets digitally. The application enables municipal authorities to systematically collect and monitor data concerning parking lot utilization, facilitating the analysis of driver behavior. In light of the data obtained, the city is in a position to recalibrate its parking policy. Another significant technology that has recently been implemented in the city is parking control, which utilizes a specialized CamCar monitoring vehicle that employs artificial intelligence. This modified vehicle is capable of monitoring up to 1,000 parking spaces per hour, a significant improvement over the capacity of the city police, who previously managed to inspect approximately 600 spaces per day. The vehicle is equipped with six cameras for scanning cars, as well as a GPS locator, a communication unit, and an evaluation unit.

By evaluating the camera recordings, artificial intelligence algorithms are able to recognize the license plates of vehicles parked in the relevant spaces. These plates are then compared with a database. The system's evaluation process is predicated on a comparison that is subsequently utilized to determine whether a vehicle bearing a specific license plate is authorized to park in a designated area. Additionally, the municipality has implemented smart street lamps that adjust their lighting to current outdoor light conditions, thereby enhancing the overall quality of life for residents and visitors alike. These street lamps also serve as Wi-Fi hotspots, providing free internet access to the public. Additionally, cameras have been installed that

can analyze video recordings and monitor traffic or record criminal activity by analyzing the recordings (Holotová et al., 2023; Trencin.sk, 2025).

The city of *Trnava* has once again demonstrated its commitment to sustainable urban development by implementing a bicycle-sharing program. This initiative not only promotes eco-friendly transportation options but also contributes to the reduction of traffic congestion, thereby enhancing the quality of life for residents and visitors alike. Furthermore, semi-underground containers equipped with sensor systems have been installed in the city to monitor container fullness and inform the city administration when they need to be emptied. Trnava, a city with a long history in Slovakia, is undergoing a gradual transformation into a modern and technologically advanced urban center. The city of Trnava has articulated a distinct vision regarding innovations in the domain of transportation. The city of Trnava has received a substantial amount of funding from the European Union for a project entitled "Smart Intersections." The modernization of 11 traffic lights in Trnava will result in the creation of a smart network of intersections, thereby enabling real-time monitoring of the traffic situation. This approach is expected to enhance traffic signal management, leading to a reduction in traffic congestion and an improvement in safety. The city of Trnava has implemented a shared e-bike system operated by Trnava City Services. In September 2018, a trial operation of the system was initiated in collaboration with Lucron Group a.s., which donated the initial 50 electric bicycles to the Trnava local government for utilization by residents within the city. The system was tested by hundreds of interested parties and subsequently set up for regular operation in the spring of 2019. Shared electric bikes represent a sustainable mode of transportation that contributes to reducing air pollution and alleviating traffic congestion in urban areas. The electric drive guarantees a serene and pollution-free journey. The city's shared electric bike system

comprises 146 bikes and 68 physical and virtual charging stations. Since 2019, the company has also operated an automatic bicycle rack at the train station. Autonomous vehicle systems are poised to play a pivotal role in the evolution of smart mobility. If these initiatives are to facilitate more efficient transport, enhance safety, and contribute to the decarbonization of transport, they cannot be regarded as a mere matter for the future.

The initial phase of data collection was executed by research teams from two Slovak Technical University (STU) faculties on public transportation vehicles in Bratislava, specifically buses and trams. The second phase is being carried out in Žilina by University of Žilina (UNIZA) using a similar model. The data from each moment of the recorded journey contains information about all occurrences with or around the vehicles on the actual route. This will facilitate the analysis of their interaction with static and dynamic infrastructure, providing a realistic basis for the development of smart mobility in cities. The collection of environmental data, including air quality, noise levels, weather conditions, human movement patterns, and traffic metrics, was initiated by sensors as part of an additional Slovak research initiative. The Synciton project utilizes a communication solution that was developed in-house.

The comprehensive framework for sustainable mobility and shared transportation in Trnava encompasses the following elements:

- Trnava is an example of a smaller city that recognizes the importance of Smart City solutions:
- Cycling infrastructure: Building new cycle paths and a bike-sharing system are priorities that support green transport.
- Digital platforms for public transport: Trnava plans to introduce a mobile app that will enable citizens to plan their journeys by public transport more efficiently (Trnavský hlas, 2023; Baran, 2019).

Another beneficiary is the city of *Nitra*, where, as in Trencin, projects have been implemented involving smart lamps with automatic brightness adjustment. The incorporation of security features, including cameras, weather stations for air quality monitoring, and fast-charging stations for mobile phones, is also underway. Concurrently, smart parking lots equipped with sensors have been implemented in select locations, and the SmartDots application is being utilized. The city undertakes a thorough examination of the data procured from the application, complemented by a meticulous analysis of traffic conditions. In addition, the city endeavors to optimize logistics and public transportation. The city is also implementing electric mobility measures, including the construction of an infrastructure of 50 charging stations over the next three years. Nitra has also adopted the Smart City concept, with a particular focus on mobility, living standards, and smart energy. The municipality's strategic plan entails the introduction of contemporary public transportation options, such as electric buses and alternative means of transport, the expansion of cycling infrastructure, and the implementation of parking regulation technologies in the city center (Holotová et al., 2023).

For instance, the city of *Žilina* employs information and communication technologies (ICT) to address its traffic congestion, minimize environmental impact, and enhance the mobility of its residents and visitors. The city of Žilina is confronted with challenges related to traffic congestion and the pervasive use of private vehicles. Among the proposed solutions are intelligent crossings, speed meters, integrated weather stations, and the Invipo platform for real-time traffic monitoring. Bike-sharing programs and electric scooter-sharing programs are also a critical component of the solution; however, they are subject to seasonal limitations. The integrated transport system, which was introduced in 2022, has been shown to enhance

the connection between different modes of transport, thereby promoting more environmentally friendly and efficient travel. The city of Žilina has demonstrated a proactive stance in pursuing grants to implement these solutions and has also engaged in the collection of substantial data from sensors. This data serves as the foundation for strategic decision-making processes related to transport and spatial planning. The project, entitled "*Modern Technologies in the City of Žilina*," aims to transform Žilina into a Smart City, characterized by the integration of modern technologies that are designed to enhance the quality of life for its citizens. In 2021 and 2022, the city of Žilina implemented project activities in several areas. The primary focus of this initiative pertains to the management of traffic regulations, the utilization of local environmental indicators for decision-making, the implementation of intelligent public lighting systems, the enhancement of energy efficiency, and the promotion of enhanced safety in public spaces. The project's scope also encompassed the development and management of public policy, a task for which the collection and evaluation of data from multiple systems were deemed essential. As part of the smart transport project, plans were developed to construct nine new smart intersections in areas with higher traffic density, including Vlčince, Staré Mesto, Závodie, and Bôrik. These intersections will cater to both motor vehicles and cyclists, as well as pedestrians. The city of Žilina has implemented a program to enhance road safety by installing eight speed cameras in high-risk sections of the city, including Bôrik, Hliny, and Vlčince. Furthermore, eight counters have been installed to record traffic intensity at selected locations, including Bytčica, Strážove, Budatín, Vlčince, Solinky, Hájik, and Staré mesto. In an effort to enhance public safety and maintain order in Žilina, a comprehensive surveillance system has been implemented, comprising 19 rotating cameras equipped with advanced smart features, 3 fixed cameras utilizing state-of-

the-art technologies, and 20 personal cameras allocated for the municipal police. Concurrently, a state-of-the-art monitoring center equipped with a substantial screen has been constructed, enabling law enforcement officials to more efficiently oversee and evaluate the city's security landscape. As part of the project, 14 modern weather stations were installed in the city of Žilina to monitor various climatic and environmental parameters. The strategic placement of these stations ensured comprehensive coverage, providing a comprehensive picture of the state of the air and the environment in various city districts, including industrial zones, the city center, parks, and residential areas. The city of Žilina pioneered the implementation of an advanced system in Slovakia, prioritizing public transportation vehicles at traffic intersections. Consequently, buses operating with delayed schedules are programmed to receive green lights, enabling them to reach their destinations more expeditiously (Bubelíny, Kubina, Varmus, 2024; Aktuality.sk, 2021).

The city of *Košice* has implemented a unique public transportation ticketing system via a mobile application that integrates online public transportation location, expedited ticket purchase, and access to shared transportation.

This system encompasses a fleet of over 700 shared transport vehicles, including electric scooters, bicycles, and scooters, along with more than 180 charging stations strategically located throughout the city. Smart Lighting and Digitalization in Transport in Košice:

- Košice, as the second largest city in Slovakia, is focusing on modernizing public lighting and transportation.
- Smart lighting: Energy-efficient LED lamps equipped with sensors have been shown to facilitate automatic activation or dimming in accordance with prevailing conditions, thereby contributing to electricity conservation.

- The digitalization of transportation is a subject of increasing importance in the contemporary era. Košice plans to introduce traffic management as per the analysis of sensor data, which is expected to improve traffic flow and increase road safety (ANTIK Technology, 2025).

The city of *Bratislava* has been developing the Smart City concept through a variety of projects aimed at improving the quality of life of its residents and the efficiency of its city management. The most significant of these is the launch of the Bratislava Account platform, which integrates services such as digital tax payments, filing tax returns, digitalized requests for opinions, and online ticket purchases. The platform has already amassed an extensive user base of nearly 29,000 individuals, providing a consolidated digital environment for municipal services. Another pivotal project is the Open Data Portal, which facilitates access to municipal data, thereby enabling more efficient decision-making and planning. The city has also introduced innovative approaches in urban studies (e.g., MUŠ Mlynské Nivy) and has prepared strategic documents such as SECAP, which are aimed at solving environmental challenges such as heat islands and flooding.

The plans for the period until 2030 include the modernization of the city's transport network, the digitalization of spatial planning, electronic waste registration, and the implementation of smart lighting systems. The pilot projects encompass the modernization of municipal police communications and the integration of interactive technologies and augmented reality in the design of public spaces. The number 144 will be recorded as a significant milestone in the history of Slovakia's development of smart mobility. The bus of the Bratislava Transport Company, which operates as a line with this number on the Koliba to Kamzík route, became the first vehicle for collecting traffic data in regular traffic in April 2021. The

creation of unique datasets is a practical output of the cooperation between the Slovak University of Technology (STU) and the University of Žilina with technology companies, as well as the Ministry of Transport and Construction of the Slovak Republic.

This cooperation is part of a smart mobility development project with the Ministry of Investments, Regional Development and Informatization of the Slovak Republic. Bratislava, as the capital of Slovakia, has assumed a leading role in the implementation of Smart City solutions. The following projects have been meticulously planned:

- Smart parking: The objective of this study is to propose a system that would facilitate the monitoring of available parking spaces and the navigation of drivers to the nearest available spaces. The objective of this project is to mitigate the environmental and societal challenges posed by the search for parking, which is a major contributor to traffic congestion and CO2 emissions. The capital of Slovakia, Bratislava, has emerged as a leader in the field of Smart City solutions, particularly in the realm of smart parking. This system utilizes sensors to monitor the availability of parking spaces in real time. Citizens can utilize a mobile application to ascertain the location of available free parking spaces, thereby reducing the time spent seeking parking and consequently decreasing traffic emissions. The project has been instrumental in enhancing traffic flow in the city's central districts and mitigating the stress associated with locating parking spaces.
- Air monitoring: The integration of sensors to assess air quality will facilitate the identification of pollution sources by the city and enable the implementation of measures to enhance air quality (Schreinerová, 2024).

### 5.3.3 Implementation of local Smart City mobility components in Slovak cities by private companies

In an effort to facilitate Slovakia's entry into the realm of Smart Cities, several corporate entities have collaboratively initiated a joint venture. Their experiences from Slovakia and abroad indicate that the "Smart City" concept is not merely a passing trend but rather a comprehensive approach to enhancing the simplicity, sustainability, and environmental friendliness of urban life.

***SYGIC***

The Sygic Smart Mobility Platform has been developed for the purpose of addressing traffic congestion. The integration of central navigation and traffic management systems has been demonstrated to enhance the efficiency of all modes of transportation within urban environments, encompassing both private vehicles and public transit options, as well as non-motorized transportation such as bicycles. The platform enables city management to assign priority levels to specific types of transportation during designated periods. Commuters have access to a mobile application that provides them with the most efficient route to their designated parking space at any given time. The Smart Modern Platform is a contemporary solution designed to alleviate traffic congestion and enhance the efficiency of transportation management in urban areas. The platform enables the optimization of transportation from automobiles to bicycles and public transportation. This system enables urban areas to assign priority levels to specific types of transportation during designated periods, thereby enhancing the efficiency and fluidity of urban mobility. A mobile application has been developed for residents, providing real-time guidance on optimal route navigation to locate available parking spaces. This comprehensive approach contributes to

reducing emissions, facilitating mobility in cities, and improving the daily lives of residents. The primary advantages of this approach include the capacity to analyze and predict the impact of infrastructure modifications and enhancements to public transportation routes. Additionally, it facilitates the optimization of waste collection, street cleaning, and traffic light configurations.

***SEAK***

SEAK Smart City is an innovative public lighting management system that has been demonstrated to reduce energy consumption while enabling direct charging of electric vehicles from lampposts or air monitoring stations. The financial savings from this investment will be sufficient to cover the cost of the new lighting system and will provide a financial cushion for other smart home technologies. For instance, the direct charging of electric vehicles from lampposts, the implementation of air monitoring systems, and related applications are notable examples. The primary advantages encompass cost savings, dependable communication, and enhanced lighting quality. These benefits are achieved by leveraging the existing electrical cables for reliable communication and ensuring the availability of sufficient lighting. References: The following cities have been identified: Východná (Slovakia), Letohrad (Czech Republic), Sevilla (Spain), Tel Aviv (Israel), and Kiev (Ukraine).

***INVIPO (ALAM)***

Invipo is a flexible and open platform for integrating technologies, systems, and services in urban areas and on thoroughfares. It integrates data from disparate technologies and systems into a unified entity, thereby facilitating comprehensive monitoring of outputs and effective management

of smart projects. This platform integrates urban technologies, thereby enabling effective management and improved decision-making as per hard data. The project's reach extends to cities such as Žilina, Trnava, Prešov, and international locations including Dubai and Sofia, reflecting a global engagement. The primary advantages of this approach are as follows: The objective of this project is to integrate all urban systems and technologies into a centralized application. The process of decision-making is enhanced by the utilization of empirical data, encompassing trends, statistical analyses, and comprehensive reports. The unified management and control platform has been developed for the management and maintenance of urban technologies. The objective is to enhance the quality of life of citizens through the transformation of data into information that is visually appealing and pertinent. References: The following cities were included in the study: Žilina (SK), Trnava (SK), Prešov (SK), Zlín (CZ), Kladno (CZ), Olomouc (CZ), Legnica (PL), Sibiu (RO), Sofia (BU), Dubai (UAE), and Izmir (TK).

***GOSPACE***

The R&D company's primary focus is on the development of highly qualified solutions within the domain of SmartCity, with a particular emphasis on static transport. The solution, dubbed "SPOT" (Smart Parking Organization Technologies), has been demonstrated to address a wide range of parking-related challenges, encompassing its planning and operation. The system for smart parking is designed to digitize parking, navigate drivers to available spaces, and improve parking policies. The implementation of pilot projects is currently underway in ten locations across Slovakia, the Czech Republic, and other countries. The primary advantages of this approach are as follows: The transition of parking from analog to digital formats has the potential to enhance the efficacy of parking policy

enforcement at the municipal level. This transition also facilitates the navigation of drivers to available parking spaces, thereby improving the efficiency of parking resources. References: The project has been implemented in ten locations across Slovakia, the Czech Republic, and the United States. Additionally, a pilot phase was conducted in Sweden, Latvia, and Bulgaria.

***MYCROFT MIND***

Intelligent Sensor Data Analytics is a software solution that has been developed for the purpose of collecting and advanced processing of sensor data. This is achieved by the implementation of adaptive algorithms and machine learning. The identification of anomalies and trends in measured data is paramount for the prediction of electricity consumption behavior. Furthermore, the classification of consumers according to their behavior is essential for effective decision-making. This analytical software solution utilizes machine learning to process sensor data. The primary objective of this study is to develop a model that can effectively predict energy consumption and manage charging stations for electric vehicles. The primary advantages encompass the aggregation and sophisticated online processing of voluminous data, intelligent metering, the prediction of methods for adaptively managing urban consumption, the detection and segmentation of electric vehicle (EV) charging models, the identification of prospective EV charging stations, and the estimation of energy consumption savings. References: The following companies are represented in this study: ČEZ Distribuce a.s. (CZ), E.ON (CZ), PRE (CZ), Škoda Auto (CZ), and Deloitte (INT).

***PARKDOTS - POSAM***

ParkDots is a system that provides drivers with real-time information regarding the availability of parking spaces, navigates them to an available space, and processes parking payments. The primary function of this system is to assist municipalities in the implementation and optimization of parking policies, the effective control of parking fees, and the determination of parking eligibility. ParkDots (POSAM) is a system that monitors parking space occupancy and processes parking payments. The company's operational scope encompasses Bratislava, Trencin, Amsterdam, and other metropolitan areas. The following are the primary benefits: This system facilitates expeditious and secure mobile payments for parking in both street and barrier-controlled locations. It also enables the control of parking eligibility, occupancy monitoring, and residential parking. References: The following cities have been identified as having relevance to the subject in question: Bratislava (SK), Trencin (SK), Nitra (SK), Prievidza (SK), Liptovský Mikuláš (SK), Dolný Kubín (SK), Amsterdam (NL), Utrecht (NL), Rotterdam (NL), Chania (GR), and Hamburg (DE).

***THE GREEN BICYCLE***

The Slovak system, in its original form, facilitates the implementation and operation of a comprehensive bicycle-sharing program in urban municipalities, providing residents with access to this service. The systems are designed in one of two ways. In the first configuration, the systems are station-based. In this configuration, citizens can access bicycles at selected stations. This design effectively eliminates the risk of bicycle vandalism. In the second configuration, the systems are station-free. The network of stations is characterized by its density and alignment with the specific requirements of the city, with each station typically offering ten bicycles, four

of which are parked and six available for use. This Slovak shared bicycle system is designed to operate either as a station-based model or as a station-free system. It is currently operational in cities such as Prievidza and Bojnice (ANTIK Technology, 2025; Tengler, Majerčáková, Piroš, 2023; Baran, 2019; Holotová, 2023; Kona, Guťan, Horváth, 2020).

## 5.4 Opportunities, recommendations and suggestions for improving Smart City policy in the area of mobility and transport

This subchapter identifies the primary challenges cities encounter when implementing these solutions, including technological, legislative, and economic constraints. A thorough examination of the findings offers a comprehensive perspective on the potential contributions of smart mobility and transportation to the achievement of sustainability objectives and the enhancement of urban quality of life. Smart mobility has the potential to leverage artificial intelligence algorithms to enhance the logistics and serviceability of the territory. This phase is currently in its nascent stages, but it possesses considerable potential for the future of Smart Cities. In this system, vehicles are divided into six classes as per the degree of autonomy. The first class is characterized by the absence of any driver intervention. In the sixth class, the driver's role is minimal, and the vehicle is capable of navigating to the destination with minimal input from the user. The path to the final category will be arduous, as two crucial components are absent: long-term testing and legislation, each of which must be approved individually by each state. A discussion of the emergence of entirely novel modes of transportation is also possible. For instance, a drone capable of autonomous operation has been tested internationally. This drone is equipped

with a system that enables a single adult user to enter a designated location, after which the drone, connected to an application, autonomously navigates to the intended destination. Another proposed solution is the high-speed Hyperloop transport system, which utilizes pressurized capsules to traverse vacuum tube tunnels (Svítek, Postránecký, et al. 2018).

In the context of *opportunities and challenges* in urban and rural areas, smart mobility represents a pivotal component of the modernization of transport systems, with implementation differing between urban and rural areas. In metropolitan areas, the emergence of smart solutions is propelled by three key factors: high population density, robust technological infrastructures, and economic strength. Conversely, in rural areas, smart mobility faces challenges stemming from low population density, limited infrastructure, and fewer sources of financing. Notwithstanding these constraints, judiciously conceived innovations have the potential to facilitate connectivity and accessibility in more remote regions. The Internet of Things (IoT) and the flexibility of systems in rural areas enable the efficient collection and processing of transport data, resulting in the adaptation of services to user needs. In rural areas, pilot projects such as RUMOBIL have demonstrated that the implementation of flexible transport systems, including dynamically planned connections and on-demand transport systems, can substantially enhance the accessibility of services for dispersed communities. These solutions have been demonstrated to reduce population isolation, improve access to healthcare and employment, and support local economic development. Rural areas are confronted with challenges that are distinct from urban areas and are linked to a lack of fundamental infrastructure and limited resources. In such instances, conventional transportation models often prove ineffective due to the low population density, necessitating the implementation of specialized approaches. Examples of such approaches

include community buses and shared mobility services, which have been shown to more effectively address the needs of residents. However, the implementation of smart solutions is hindered by low technological readiness, which includes limited access to high-speed internet and digital technologies. In regard to the future of rural regions, the integration of smart mobility systems has the potential to effect a fundamental transformation. These systems combine flexible transportation solutions, the Internet of Things (IoT), and support for local communities.

Investments in infrastructure that will enable sustainable mobility, as well as policies that will promote affordability and equity of access, are essential. The integration of autonomous shared vehicles, particularly within the framework of on-demand transportation systems, has the potential to contribute to cost reductions and the enhancement of quality of life for residents in more remote locations (Hassan et al., 2023; D'Alberto & Giudici, 2023).

The implementation of the Smart City concept in the field of mobility and transport requires constant innovation and adaptation to the needs of the inhabitants. The following suggestions are as per the analysis of successful implementation of Smart City in the field of mobility and transport (Brčić, et al. 2018; D'Alberto, et al. 2023; Lee, et al. 2023; Narayanan, Antoniou, 2023; Porru, et al. 2020):

1. Strengthening digitalization and system integration
    - *Integrated mobility platforms*: Creating a single digital system that includes all forms of transport, including public transport, shared vehicles and bicycles, with the possibility of trip planning and payment.
    - *Big data analytics*: Using IoT and AI to analyze traffic data, predict congestion and optimize routes in real time.

- *Better accessibility*: Introducing applications with enhanced features for people with disabilities, such as navigation for the blind or assistance for people with reduced mobility.

2. Promoting sustainability and green transport
    - *Transition to low-emission transport*: Increasing investment in electric buses and building infrastructure for charging electric vehicles.
    - *Supporting active mobility*: Expanding cycle paths, pedestrian zones and introducing initiatives to support cycling and walking.
    - *Smart environmental zones*: Creating low-emission zones with dynamic vehicle access control as per emissions.
3. Developing autonomous and shared transport
    - *Testing autonomous vehicles:* Pilot projects of autonomous buses or taxis in specific areas to increase safety and efficiency.
    - *Supporting car sharing and bike sharing*: Introducing flexible car and bike sharing systems that are affordable and environmentally friendly.
    - *Cooperation with technology companies*: Partnerships with innovative companies to develop and test advanced solutions.
4. Improving infrastructure and smart solutions
    - *Intelligent transport systems (ITS*): Implementing adaptive traffic lights that adjust traffic according to real-time data.
    - Parking optimization: Smart parking systems that navigate drivers to available spaces and reduce the time spent searching for parking.
    - Traffic monitoring: Implementing sensors to monitor traffic flow, noise levels and air quality.

5. Strengthening cooperation between sectors

- Public-private partnerships: Cities work with technology and transport companies to finance and implement new solutions.
- Public engagement: Creating participatory platforms where residents can propose improvements and express their needs.
- International cooperation: Sharing knowledge and experiences with other cities that have successfully implemented smart solutions.

As per the analysis, the following key success factors can be identified:

- Public policy support: Financing and legislation that support the implementation of Smart City technologies.
- Community involvement: Acceptance by residents and their active participation.
- Technological integration: Compatibility between different systems and platforms.
- Emphasis on sustainability: Reducing negative environmental impacts.

In the domain of Smart Cities, challenges associated with technical and infrastructural issues have emerged as pivotal factors influencing the success of implementation. Many cities encounter difficulties in modernizing their existing infrastructures, which often prove incompatible with emerging technologies and solutions. Smart City technologies, including intelligent transport systems, air quality monitoring systems, intelligent parking systems, and IoT devices, necessitate a robust technical infrastructure and a high level of interoperability between different systems. In urban areas with obsolete infrastructure, the implementation of novel digital technologies is often impeded by the necessity of extensive reconstruction. This endeavor necessitates a substantial financial investment and a considerable time

commitment. Furthermore, the integration of disparate systems (e.g., the interconnection of traffic and security systems) can pose significant technical challenges. In practice, this necessitates that cities must address the issue of compatibility between legacy and emerging technologies. For instance: In the case of Bratislava, the implementation of new technologies in the field of transportation, such as intelligent traffic lights or automated traffic management systems, faced challenges with integration into existing infrastructures. This assertion is equally applicable to the domain of smart lighting, wherein, in specific regions of the city, the necessity arises for the modernization of electrical networks. Smart mobility and intelligent transport have become significant components of the Smart City concept, with the objective of enhancing the quality of life for residents and addressing the challenges posed by urbanization and sustainability. The successful implementation of smart mobility and intelligent transport has demonstrated that modern technologies have the potential to significantly enhance the socio-economic quality of life of residents. However, such implementations necessitate comprehensive planning and a systematic approach. The analysis of successful implementations of smart mobility and intelligent transport was as per a comprehensive review of relevant professional articles and scientific publications.

## 5.5 Summary

To sum up, the present study examined the components of Smart City policy with regard to mobility and transportation, with a particular focus on their effect on the socio-economic quality of life of residents. The findings indicated that smart mobility and transport solutions, including digital platforms, intelligent transport systems, shared mobility, and transport electrification, have the potential to enhance the efficiency and sustainability

of urban transport systems. Concurrently, it was demonstrated that technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analysis facilitate real-time transport optimization, emission reduction, and enhanced accessibility for all residents. The study identified several challenges and problems in the implementation of Smart City mobility solutions. These include elevated financial requirements, technological limitations, legislative barriers, and the necessity for public acceptance. A coordinated approach is necessary from local governments, technological partners, and residents to address these factors. The enhancement of mobility and transportation within the framework of Smart City mobility holds the promise of elevating the quality of life for residents, while concurrently fostering economic growth and environmental sustainability. However, to reap the full benefits of these opportunities, it is imperative to persist in the exploration of novel technologies, to devise flexible project financing mechanisms, and to foster collaboration among stakeholders. As previously discussed, the evolution of urban areas into Smart Cities is poised to emerge as a significant real estate sector in the future. This is due to the fact that Smart City mobility solutions are well-positioned to address the myriad challenges that are projected to emerge in the future. The effective operation of Smart City mobility hinges upon the integration of smart mobility services. The viability of Smart City mobility is contingent upon the presence of smart mobility, and conversely, the effectiveness of smart mobility is predicated on the existence of Smart City mobility. The inevitable convergence of these two platforms is imperative for addressing the challenges posed by future urban centers, namely, Smart Cities.

# CHAPTER 6. SMART WASTE MANAGEMENT - A CLEANER FUTURE

A significant domain encompassed by this concept pertains to the management of waste and the principles of a circular economy. Achieving sustainable waste management and recycling is imperative for reducing environmental impacts, conserving resources, and minimizing waste. The integration of Smart City principles with the circular economy paradigm presents a significant opportunity for cities to effectively address pressing challenges related to high waste production, low recycling rates, and inadequate infrastructure for waste processing. This chapter is devoted to an analysis of the elements of the Smart City concept in the domain of waste and circular economy, with a particular focus on cities in Slovakia and Europe. The objective of this study is to examine the planned implementations, identify the benefits, limitations, and problem areas, and concurrently present opportunities for improving the socio-economic quality of life. The objective of this paper is to compare practical experiences and successful projects in Slovakia and European Union countries to identify specific recommendations for more effective integration of Smart City principles into the area of waste management.

## 6.1 Definition and analysis of the concept of Smart City policy in the field of circular economy and waste management

The concept of a circular economy is predicated on an economic model that prioritizes the minimization of waste, the reuse of resources, and the prolongation of product life. The objective is to establish a closed-loop system in which materials and products are reused after their initial use,

thereby reducing the adverse environmental impact. This approach replaces the conventional linear model, in which products are manufactured, utilized, and subsequently discarded as waste. The circular economy is predicated on the reuse of raw materials and materials. This approach is intended to conserve natural resources, reduce waste, and limit pollution. As stated by MIRRI (2023), an analysis of review articles in the field of waste management has revealed a variety of research directions, including technological, sociological, geographical, and economic dimensions. The multifaceted nature of waste management research is reflected in the following categories: technological innovation in solid waste management, electronic waste (e-waste) management, medical and pandemic waste management, waste-to-energy technology, zero waste management, municipal solid waste management, construction and demolition waste, global trends and analyses related to waste management, behavioral and business aspects, sustainable waste management, and local waste management (Aasavari, 2022; Ali, et al. 2020; Gomathi, et al. 2020).

The concept of Smart Cities emerged as a response to the pressing challenges of waste management and the promotion of sustainability. The primary focus of this research is the utilization of digitalization, particularly artificial intelligence, in environmental technologies, with a particular emphasis on the potential contributions of automated waste recycling to the creation of a more sustainable environment. A critical step in this process is the systematic classification of waste into distinct categories and types. This categorization has been demonstrated to enhance the overall recycling process, thereby increasing its efficiency. Consequently, there is an increasing demand for intelligent sorting systems that facilitate more efficient and intelligent recycling. Concurrently, it underscores the significance of automated waste recycling and its contribution to sustainability, which results

in enhanced overall efficiency of a Smart City and contributes to achieving environmental objectives. Machine learning plays a pivotal role in automated sorting techniques, enhancing the accuracy and quality of waste sorting. Beyond navigation and tracking capabilities, the analysis and optimization of waste processing and the required information would enhance the overall efficiency of waste management by improving waste collection as the program progresses. In the context of leveraging ML (Machine Learning) and IoT (Internet of Things), the waste management system prioritizes the monitoring and collection of waste through the utilization of smart waste bins, which are equipped with sensors and communication technologies. These bins are equipped with monitoring systems that continuously assess waste status and transmit the collected data to a centralized cloud server. This system has been developed to optimize waste collection by calculating the fastest route for garbage trucks and providing information via a mobile and web application. The application emits alerts when bins are full and facilitates dynamic route planning, thereby enhancing collection efficiency. The implementation of cloud technology facilitates data management and the integration of new services, thereby contributing to the recycling of materials and the reduction of waste sent to landfills. This system also assists cities in optimizing their resources and enhancing the quality of life for their residents, as demonstrated in Figure 6.18. (Xiangru, 2022; Aarthi, Bhuvaneshwaran, 2021; Ajwang, 2021).

Smart waste management is defined as a system that employs technology to optimize the waste collection process, while reducing costs and promoting environmental sustainability. These systems are equipped with the Internet of Things (IoT), a monitoring technology that captures and collects data in real time, thereby facilitating the optimization of waste collection. Given the imperative for population growth, it is incumbent upon us to

optimize waste management, reduce waste collection costs, and streamline the entire process.

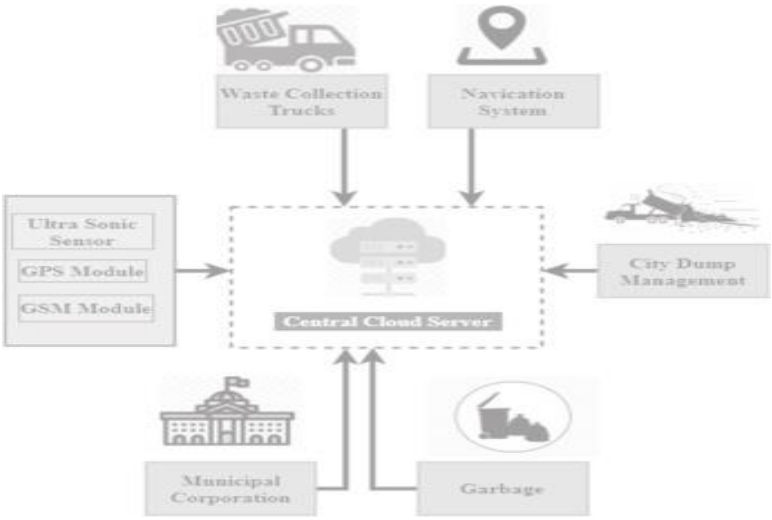



Figure 6.18

Waste management scheme in a Smart City

Source: Xiangru (2022)

*Circular economy maps* of cities are online maps that designate locations in various Slovak cities, with the objective of assisting residents in reducing their waste production and adopting a more circular approach to their daily lives. The map delineates collection yards, packaging-free stores, reuse centers, clothing upcycling studios, various repair shops, and rental shops. The residents of these cities possess a superior understanding of the availability of these places, facilitating the facilitation of resource sharing, repair, and circularity. This, in turn, enables municipalities to enhance their

circularity rates. The integration of Smart City elements within the domain of waste management is exemplified by the implementation of *smart waste bins*. Municipal waste containers are equipped with an intelligent sensor that is designed to detect the container's fullness. The information is then transmitted to specialized software that processes it, evaluates it, displays the fullness status, and calculates the optimal route for waste collection in the city (see Figure 6.19; Stannard, 2021; Kristoffersen et al., 2020).


Figure 6.19
Waste bin fullness detector
Source: Stannard (2021)

In March of 2020, the European Commission adopted a new Circular Economy Action Plan (CEAP), which is a key element of the European Green Deal, a new strategy for sustainable growth in Europe. The plan is consistent with the EU's objective of transitioning to a circular economy, a shift that is expected to reduce pressure on natural resources, stimulate sustainable economic growth, and generate new employment opportunities. This initiative is a crucial component in the broader effort to achieve climate neutrality by the year 2050 and to halt the ongoing biodiversity loss. The Action Plan encompasses initiatives that span the entire life cycle of products. The emphasis of the workshop was on the design of products,

the promotion of circular economy processes, and the facilitation of sustainable consumption. The objective is to minimize waste and ensure that resources remain in the European economy for as long as possible. The strategy encompasses both legislative and non-legislative initiatives, focusing on domains where EU-level action yields substantial added value. This approach is predicated on the promotion of sustainability, innovation, and resource efficiency throughout the European Union. The international and European framework provides the basis for adopting national measures to support the transition to a circular economy (European Commission, 2025).

In the context of *Slovakia's strategic documents concerning the circular economy*, a primary and pivotal document endorsed by the Slovak government is the "Vision and Development Strategy of Slovakia until 2030," alternatively referred to as "Slovakia 2030." The creation of the document was predicated on the Slovak Republic's accession to the United Nations' 2030 Agenda for Sustainable Development. This initiative constitutes a long-term strategy for the sustainable development of the state, which remains unaffected by the vicissitudes of any political election cycle. The objective of this initiative is to enhance the predictability of public policies, optimize the utilization of public resources, and foster stability within the business environment. The document, titled "Slovakia 2030," serves a dual purpose. Primarily, it functions as the fundamental implementation document of the 2030 Agenda for the Slovak Republic. Additionally, it fulfills the role of the National Regional Development Strategy. In the context of Slovakia, the concept of a circular economy is gaining prominence, particularly in the context of climate change and the mounting imperative for environmental protection. The government has adopted a Circular Economy Strategy, which delineates specific objectives and measures to support this model in various

areas, such as waste management, recycling, production, and product design. In order to achieve waste reduction and increase recycling rates, Slovakia is gradually implementing legislative changes and EU strategic guidelines. In accordance with European standards, Slovakia has adopted an amendment to the Waste Act, which establishes obligations to recycle certain types of waste, including plastics, paper, and glass. A packaging deposit system has been implemented to support the recycling of PET bottles and cans. This system represents a significant advancement toward the establishment of a circular economy in Slovakia, as it contributes to the reduction of plastic waste sent to landfills (MIRRI SR, 2023).

*The 2030 Environmental Strategy* prioritizes enhancing Slovakia's environmental conditions, with a particular focus on the integration of the circular economy and the optimization of waste management. This strategy is a tool for achieving the country's environmental goals in line with European standards and policies. The 2030 Environmental Strategy prioritizes the reduction of landfill waste and the promotion of recycling. A primary objective is to attain a recycling rate of 65% for municipal waste by the year 2030, along with a substantial reduction in the quantity of waste disposed of in landfills. The introduction of modern technologies is imperative to optimize waste management processes and increase recycling rates. As with previous documents, the Environmental Strategy advocates for the utilization of technological innovations to enhance the efficiency of waste management. Emphasis is placed on a digitalization and the implementation of automated waste collection and sorting systems as key strategies to minimize manual intervention and enhance operational efficiency (Ministry of Environment of the Slovak Republic, 2019).

Despite the progress achieved, Slovakia faces several challenges associated with implementing the circular economy in practice. The primary

challenges encompass the necessity to enhance infrastructure for waste collection and recycling, to elevate consumer awareness, and to encourage modifications in business practices. There is still a need for citizens to be more involved in waste separation and responsible waste management. Moreover, there is a necessity to enhance the legislative frameworks that would facilitate the implementation of this model in practice. A critical area necessitating prompt enhancement pertains to the management of waste.

Presently, the majority of waste collection systems are antiquated, resulting in collections that are either superfluous or delayed. The annual collection costs have increased by 70%, largely due to the presence of unnecessary collections. Inadequate route planning results in congestion, thereby increasing the amount of fuel required for the execution of collections. This results in a 50% increase in the overall carbon footprint. The development of more efficient routes for garbage trucks, facilitated by the integration of advanced waste management technologies, has emerged as a promising solution to address these challenges. The necessity of emptying trash bins can be ascertained through the implementation of sensor technologies.

This dynamic and adaptable waste management system has the potential to benefit businesses, organizations, and citizens alike (Aasavari, 2022; Kumar, et al. 2021). At the core of these technological advancements is the Internet of Things (IoT), which has emerged as a significant catalyst for Smart City initiatives worldwide. The Internet of Things (IoT) has emerged as a transformative technology, driving advancements in various sectors, including infrastructure, waste management, transportation, and the enhancement of human life quality. This transformation is further facilitated by advanced Internet of Things (IoT) communication technologies, which enable the integration of various components to enhance city governance and

services for residents. The implementation of the Internet of Things (IoT) in Smart Cities has the potential to optimize public services, including transportation, water management, smart buildings, healthcare, education, and more. This transformation of society into smart communities is a significant development. A critical domain in which this convergence finds application is waste management (Aasavari, 2022; Ajwang, 2021).

The transition to a circular economy — defined as a production and consumption model as per closed material flows and a substantial separation between resource consumption and economic growth (so-called decoupling) — would significantly reduce resource demand and its impact, in line with the Sustainable Development Goals. Cities, as centers of economic activity and innovation, are at the forefront of this transformation. These activities are responsible for a significant proportion of greenhouse gas emissions, two-thirds of total energy demand, and 50 percent of waste. Consequently, they are required to assume a pivotal function in the implementation of circular economy solutions, with the objective of optimizing their impact.

A comparison of Slovakia with the European average reveals that Slovakia's innovation rate stands at 64%, which is indicative of a relatively high level of innovation in the country. The Slovak Republic has demonstrated notable advancements in certain domains, while concurrently exhibiting a decline in other sectors, particularly with regard to environmental technologies. This figure signifies one of the most substantial annual declines recorded. The Slovak Republic's overall innovation capacity is ranked twenty-third. According to the European Innovation Scoreboard 2022, Slovakia's circularity rate stands at 12.2%, a figure that falls considerably below the EU average. The following is a list of innovations that local governments can introduce within the framework of the circular economy. The Circular Cities Declaration Report (CCDR) identified eight trends within

the framework of the circular economy of cities and municipalities (Kumar et al., 2021; Ajwang, 2021; Stannard, L., 2021):

a) The increasing number of circular economy initiatives in Europe to support cities.
b) Cities are preparing and adopting strategies and plans to manage the transition to a circular economy.
c) Cities are investing in new technologies and infrastructure to close material flows.
d) Cities are using public procurement as a tool to reduce their environmental footprint and enable the transition to a circular economy.
e) Cities are setting up their own innovation programmes and preparing innovation projects to enable the transition to a circular economy.
f) Cities are raising awareness and encouraging citizens to take ownership of their cities.
g) Cities are working towards a higher level of circularity in the construction sector.
h) Cities are creating more regenerative local food systems.

## 6.2 Circular Economy and Waste Management Smart City policy success stories analysis and best practices overview in EU and Slovakia

Smart City initiatives pertaining to waste management have emerged as a pivotal concern in numerous global metropolitan areas. The European Union is widely regarded as a global leader in implementing innovative

solutions to enhance waste management and optimize urban systems. In addition to Barcelona and Copenhagen, which have previously been referenced, there are other European cities that exemplify the successful implementation of technologies in this domain. In the domain of waste and circular economy in the European Union, there are numerous successful projects that concentrate on enhancing waste management, recycling, and the transition to a circular economy. These projects are frequently supported by European funds and national initiatives. In this chapter, we will examine several Slovak and European cities that have adopted the implementation of Smart City in the field of circular economy.

### 6.2.1 Successfully implemented projects and best practices within the EU

Examples of innovative approaches to the circular economy in the EU are presented to demonstrate the possibilities that can be implemented in Slovakia at the level of local governments. The initial illustration is provided by the *Circular Copenhagen Innovation Platform*, situated in *Denmark*. This innovation platform, operated by the city of Copenhagen, aims to develop solutions for the present challenges of the circular economy. The Circular Copenhagen project aims to establish novel partnerships with prominent national and international industrial and academic stakeholders with a focus on developing a circular economy in Copenhagen (ICLEI Europe, 2025).

*The Circle City Scan* tool enables local governments to identify and prioritize circular economy opportunities for their city or region. These opportunities are determined as per socio-economic and material flow data, relevant case studies in the circular economy, and user input on which sectors, materials, and areas of impact are prioritized in local programs. This tool is informed by the expertise of Circle Economy, which has assisted cities and

regions in developing circular economy action plans over the past five years. Noteworthy examples include cities such as Amsterdam, Glasgow, Basel, Almaty, Philadelphia, and Prague, among others.

*Amsterdam (Netherlands)* has emerged as a global leader in the realm of smart waste management and sustainability. The city has implemented a smart waste collection system that utilizes sensors to monitor the fullness of containers and optimize the routes of waste collection vehicles. This system has been demonstrated to reduce fuel costs and CO2 emissions. The city has also developed innovative solutions for waste recycling, focusing on minimizing waste going to landfill and promoting the reuse of materials. Another noteworthy initiative is the establishment of an electronic waste sharing platform, which enables citizens to publish waste that can be reused, thereby reducing the overall volume of waste in the city (ICLEI Europe, 2025).

*Hamburg (Germany)* exemplifies a Smart City solution that prioritizes waste management. The city has implemented a smart waste collection system that uses IoT sensors to monitor the status of waste containers. These sensors provide real-time information to collection services regarding the necessity of emptying containers, thereby facilitating the optimization of vehicle routes and the reduction of waste collection expenses. Moreover, Hamburg is prioritizing Waste-to-Energy technologies (incineration of waste to generate electricity) and smart processing infrastructure that supports sustainable energy solutions. This approach contributes to reducing the environmental burden and increasing the sustainability of the city (ICLEI Europe, 2025).

*Vienna (Austria)* is another exemplar of the successful implementation of Smart City solutions in the field of waste management. The city prioritizes the effective sorting of waste and the recovery of energy from waste. Vienna

has established itself as a leader in the field of organic waste recycling, implementing a system that processes waste into biogas and compost. This initiative has contributed to a significant reduction in the amount of waste sent to landfills.

This strategy is instrumental in facilitating Vienna's achievement of its zero waste objectives, which include a substantial reduction in the proportion of waste destined for landfills by the year 2030. Furthermore, the city has adopted smart technologies to oversee recycling stations and enhance the efficiency of its waste collection system. Vienna has also implemented educational programs to raise citizens' awareness of proper waste management, which has significantly contributed to improving recycling rates. Vienna has implemented a comprehensive array of waste prevention and management measures. One such facility is the Spittelau waste incinerator. This incinerator has the capacity to provide heat to more than 60,000 households in Vienna in an environmentally friendly manner on an annual basis. The process entails the incineration of solid waste in a meticulously controlled, oven-like environment, thereby facilitating effective management and reduction of waste volume.

The process of incineration has been demonstrated to effectively reduce the weight and volume of waste materials. In practice, a crane is utilized to transport the waste into incinerators for thermal recycling. The incineration process generates high-temperature exhaust gases that facilitate the conversion of water into steam. This steam drives a turbine, which in turn generates electricity. In addition to the energy produced, the facility generates 6,000 tons of scrap and 60,000 tons of slag, ash, and filter waste on an annual basis. The scrap is recycled into new metal products, the slag is used in cement production, and the ash and filter waste are used in construction and waste treatment. This supports a circular economy and reduces environmental

impact. Vienna's waste management system plays a pivotal role in the circular economy, which involves the transformation of unavoidable waste into valuable secondary raw materials.

The facility's modern amenities align with the city's objective of attaining net-zero emissions, thereby demonstrating a commitment to sustainability. Notably, this waste management system has been demonstrated to generate a higher level of carbon dioxide abatement than it releases into the atmosphere. The city of Vienna has established a comprehensive program to achieve its zero emissions target by 2040.

Figure 6.20

Spittelau Incinerator

Source: Bonus Nachos (2022)

The "smart climate city" strategy is a framework designed to guide Vienna's development in the coming decades. This strategy emphasizes climate action, resource conservation, and innovation to ensure a high quality of life for all residents. Vienna produces compost known as "Guter Grund."

This compost is produced by the city council from organic waste collected from city bins. The facility receives approximately 200 trucks on a daily basis, contributing to a total annual waste intake of approximately 700 tons. This equates to a yearly total of approximately 250,000 tons of waste. Given the commodification of waste, which is regarded as a marketable commodity, it emerges as a viable source of energy.

Figure 6.20 illustrates an incinerator that employs the most efficient technologies and processes to minimize environmental impacts and maximize energy use (Impact Hub Vienna, 2024; Bonus Nachos, 2022).

*Lyon (France)* is another European city that has implemented smart waste management solutions. This initiative was a component of a comprehensive Smart City framework, encompassing a range of technological innovations, including sensors designed for the monitoring of waste bins and intelligent waste sorting systems. Lyon has developed an advanced waste tracking system that provides city authorities with real-time information on the fullness of bins, allowing for optimal planning of collection routes.

This system incorporates a waste categorization component, facilitating enhanced recycling management and reduced landfill disposal. Lyon is also focusing on implementing innovative solutions for energy recovery from waste. The company is collaborating with numerous technology companies to develop biogas plant systems that facilitate the conversion of organic waste into renewable energy. This approach is a significant contribution to the reduction of dependence on traditional energy sources and the promotion of sustainable development. Lyon has garnered recognition for its commitment to public engagement, involving citizens in initiatives that promote environmental awareness and responsible recycling practices (ICLEI Europe, 2025).

*Oslo,* the capital of *Norway*, is widely regarded as one of the most environmentally sustainable cities in Europe. The city has implemented several innovative waste management solutions aimed at reducing waste and increasing recycling rates. The municipality of Oslo has initiated a program to install smart waste bins that are equipped with sensors capable of monitoring the bins' level of fullness. This initiative has been implemented with the objective of enhancing the efficiency of collection vehicle routes, thereby reducing fuel consumption and subsequent CO2 emissions. This waste collection system is integrated with an automatic waste sorting mechanism, thereby ensuring the more efficient utilization of recycled materials. The city of Oslo has also demonstrated a commitment to the development of a circular economy, with a focus on the utilization of organic waste as a resource for the production of biogas. This biogas, in turn, is employed as a fuel source for public transportation vehicles, such as buses. This approach contributes not only to reducing environmental impacts but also to improving air quality in the city. Furthermore, Oslo is allocating substantial resources to the implementation of smart technologies, with the objective of integrating waste management with energy solutions. This system has demonstrated notable efficacy in the conservation of resources and the reduction of the energy intensity of urban systems (ICLEI Europe, 2025).

*The CityLoops Project*, a European initiative funded by the Horizon 2020 research and innovation program, is dedicated to the promotion of the circular economy within urban centers. The objective of this initiative is twofold: first, to minimize waste, and second, to encourage the reuse of resources, with a particular focus on construction materials and bio-waste. The initiative assists municipalities in implementing sustainable strategies, evaluates solutions in pilot cities (e.g., Seville), and furnishes tools to

integrate the circular economy into urban policies. The initiative emphasizes recycling, reducing the environmental footprint, and educating cities to contribute to development and climate neutrality (CityLoops, 2024).

*Biopolus Metabolic Hubs (BioMaker)* are urban metabolic hubs that integrate circular urban infrastructure and open innovation technologies. These hubs assist cities in transitioning from the current linear system of consumption and waste to a sustainable and regenerative circular model. The development of BioMakers was predicated on the fundamental principle of water urban circulation, wherein energy, food, and waste systems are structured on a regenerative and sustainable water cycle. BioMakery is a manufacturing platform that produces intermediate products from wastewater and organic waste. These intermediate products can then undergo further processing to yield a wide range of valuable end products, including water reuse, food and feed, and biopolymers (Biopolus, 2025).

*The Circular Smart Cities Framework* is predicated on the notion that a circular city is conducive to a just transition from a linear to a circular economy in urban space. This transition occurs across different functions and departments of the city and in collaboration with residents, businesses, and the research community. In practice, this entails a transition from a "take, make, throw away" model to an economic system that prioritizes the preservation of infrastructure, products, and materials for as long as possible. The objective of this initiative is to enhance access to resources, reduce emissions, and safeguard biodiversity, in accordance with the Sustainable Development Goals. The Circular Cities Action Framework is a comprehensive strategy that urban changemakers can utilize to initiate the transition towards a more circular system. The framework is action-based, providing users with specific strategic directions and illustrating the desired outcomes of each strategy as seen in Figure 6.21 (ICLEI, 2025).

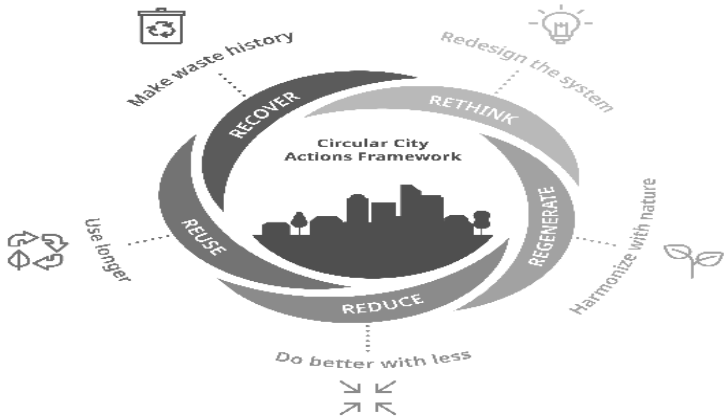



Figure 6.21

Framework of circulating urban actions

Source: ICLEI (2025)

The industrial research and development division of *Manifattura Maiano SpA*, known as Maiano Re-Lab, specializes in the development of innovative circular and textile solutions for various industries and brands. The utilization of diverse textile materials, encompassing natural, synthetic, and high-tech fibers, underscores the comprehensive approach to material selection. Maiano Re-Lab is at the forefront of sustainable industrial applications of textile residues from mass-produced consumer goods. This initiative fosters synergies among industrial sectors, reduces waste, and promotes sustainability within the sector (European Circular Economy Stakeholder Platform, 2025).

*The BOTTLE4FLEX project*, a component of the European Union's circular economy strategy, stipulates that all plastic packaging within the European Union must be 100% recyclable by the year 2030. This is a

particular challenge for packaging that comes into contact with food. The recycling of flexible PET packaging presents a challenge due to its composition of layers. In Spain, polyethylene terephthalate (PET) is the only type of recycled polyethylene permitted for use in food packaging, as stipulated by legislation regarding post-consumer recycled content. In response to this challenge, AIMPLAS, Plastics Technology Center, Covinil, and Eroski have initiated the BOTTLE4FLEX project, which aims to develop 100% recyclable flexible skinpack packaging using rPET. A "skinpack" is a type of transparent packaging that fits snugly around the product, enabling consumers to view the product directly, while manufacturers and distributors benefit from cost-effectiveness and flexibility (European Circular Economy Stakeholder Platform, 2025).

*Revivack, a Spanish enterprise*, was established by individuals who espoused the notion that the circular economy encompasses more than merely manufacturing from recycled materials; it is an imperative to adopt a mindset in which the design and production of goods should never result in waste. Nevertheless, they expressed strong opposition to the practice of greenwashing. While it is relatively simple for a company to claim that it is circular, green, and other such virtuous attributes, the veracity of such assertions is not automatically substantiated. Revivack developed a method for substantiating these claims: they implemented a transparent waste traceability system utilizing blockchain technology. The company pioneered the development of the world's first blockchain-based system, which was designed to facilitate the individual return of unwanted items to the manufacturer (or qualified entities). Consequently, these items can be recovered in an orderly, transparent, and reliable manner, thereby contributing to the promotion of a circular economy (European Circular Economy Stakeholder Platform, 2025).

The city of *Prague* has devised an alternative approach to addressing its waste management challenges. Prague residents can access contemporary information regarding waste sorting, large-volume containers, and collection yards through the My Prague – Waste web application. The municipal enterprise Prague Services has initiated the implementation of two novel functionalities:

1. The following is a list of the locations and dates of large-volume containers (LVC and Bio LVC).
2. The following is a map of collection yards, accompanied by pertinent data regarding their location and traffic patterns.

The application enables users to conduct searches as per either address or selected commodity. In certain instances, an online location is also provided, which can facilitate navigation when confronted with obstacles such as parked cars. Users are permitted to evaluate services, container capacity, and staff behavior. Suggestions are automatically transmitted to the Zmeněte.to system, from which they are addressed by the city districts and the municipality.

Evaluators who have been designated to receive correspondence at a specified email address are able to monitor the status of the solution (Property & Environment 2025). It is also possible to emphasize other solutions that have been adopted by the city of Prague. During the pilot program, 30 compression bins for mixed waste collection were installed in the city. These contemporary waste receptacles are outfitted with a photovoltaic panel and an integrated compression mechanism that processes the waste material once the bin reaches capacity. The bins are continuously connected to the internet, thereby providing real-time data on their filling level. Consequently, a single bin can accommodate up to eight times more waste than conventional containers.

The advantages of this program can be enumerated in Figure 6.22:

- Maximum use of the bin's internal space.
- Order on the city's streets.
- Optimization of waste collection costs.
- Reduction of the burden on the environment.
- Collection of data for the improvement and optimization of public spaces (Smart Prague. 2025).
-


Figure 6.22

Compression basket in Prague

Source: Smart Prague (2025)

*Madrid (Spain)* boasts the largest smart waste monitoring installation in Europe. The project entails the installation of over 11,000 sensors within containers designated for light packaging, textiles, glass, organic waste, and mixed waste. These sensors will collect data, which will then be transmitted

to a Smart Waste Management Software System, thus enabling optimized waste collection route planning. The installation of the sensors is scheduled to commence in the first quarter of 2023, representing a pivotal component of Madrid's initiative to evolve into a Smart City. The primary objective of employing smart sensors is to enhance the efficiency of waste collection while concomitantly reducing emissions, traffic congestion, and noise. A number of additional advantages have been identified, including but not limited to fuel savings, cost reductions, and shorter collection times. The project integrates state-of-the-art hardware and software solutions, including ultrasonic sensors in containers, a sophisticated waste management software system, and route planning. A pivotal component of the proposed solution is dynamic route optimization, a capability that the platform implementing the project is the sole provider capable of implementing, given its capacity to adapt the most prevalent navigation systems utilized for waste collection. This system incorporates specific considerations such as dead ends, pedestrian walkways, real-time updates, and other pertinent factors. Additionally, operators have the capacity to manually adjust routes, for instance by incorporating special collection points during periods of heightened demand, such as holidays, or by establishing one-time stops at locations such as hospitals. This comprehensive approach integrates advanced technology and flexibility, yielding an innovative solution for contemporary urban environments (Sensoneo, 2025).

In the municipality of *Horn (Lower Austria*), a pilot project was initiated in December 2018 in collaboration with Saubermacher and Austrian Glas Recycling (AGR). This initiative involves the meticulous monitoring of the filling level of nearly 600 waste glass containers (white and colored glass) that have been strategically placed at approximately 300 collection points. The primary objective of this endeavor is to enhance the efficiency of

logistics processes within the community. During the test phase, efficiency has already increased significantly. A comprehensive analysis conducted by AGR has identified the potential for significant cost and effort savings, with estimates suggesting a range of up to 30%. Mr. Hauke, the Chief Executive Officer of AGR, highlighted during the City Day event that AGR facilitates the transportation of approximately 250,000 tons of glass utilizing 70,000 containers, underscoring the substantial logistical complexity involved in this undertaking. "In the previous year, 300 of these containers were already equipped with sensor technology, and the addition of 500 collection points in Villach is planned by 2025 (SLOC, 2025).

*The Netherlands – The Ocean Cleanup* (see Figure 6.23) – this project, which is groundbreaking in nature, has been developed in the Netherlands with the objective of addressing the problem of plastic waste in the world's oceans. The project was initiated by Boyan Slat in 2013, who was only 18 years old at the time.

The underlying principle of the Ocean Cleanup initiative entails the implementation of a passive system that utilizes natural ocean currents to direct plastic debris towards the system's collection point. Subsequent to collection, the plastic is transported back to shore, where it can undergo recycling or environmentally sound disposal. The system is powered by renewable energy, thereby ensuring its sustainability and making it a viable solution to the problem of ocean plastic waste. The Ocean Cleanup project has been met with resounding success, marking a significant milestone in the realm of environmental stewardship. In a span of twelve months, the system successfully removed a total of 60 tons of plastic from the ocean.

The project has also gained global attention and inspired others to take action against plastic waste in our oceans (Sensoneo, 2024; The Ocean Cleanup, 2025).

Figure 6.23

The Ocean Cleanup

Source: The Ocean Cleanup (2025)

### 6.2.2 Planned implementations and best practices solutions in Slovakia

Cities in Slovakia, including Bratislava, Košice, Nitra, and numerous others, have initiated Smart City projects that also prioritize waste management. Within the Slovak Republic, there are several innovative projects and initiatives that are being implemented under the Smart City concept. These projects and initiatives focus on improving waste management. These projects employ contemporary technologies and systems to enhance the efficiency of waste collection, recycling, and management. They rely on innovative approaches, including the Internet of Things (IoT), big data, and sensors.

The following paragraph will provide a detailed overview of the *smart waste collection project* currently underway in *Bratislava*. The project entails the installation of both underground and above-ground containers equipped with ultrasonic sensors. These sensors are designed to detect the fullness of the containers, thereby enabling the system to recognize when the container

is full. Utilizing long-term data, the system is capable of optimizing the times and frequency of waste collection. The city of Bratislava has emerged as a leader in the implementation of Smart City solutions, particularly in the domain of waste management.

The capital city has implemented a smart waste collection project that involves the use of sensors placed in waste containers. These sensors meticulously monitor the level of fullness of the containers and provide real-time information to collection services, enabling the optimization of vehicle routes. Consequently, this approach contributes to a reduction in operating costs associated with waste collection, leading to fuel savings and a concurrent decrease in CO2 emissions. The project also supports smart parking and improves the overall efficiency of city services. This initiative has also been shown to enhance the efficiency of waste sorting, leading to an increase in the share of recycled materials. Consequently, these efforts contribute to the sustainability of the city and the protection of the environment.

The Bratislava City Strategy is the sole strategy that aims to transition to a circular economy at the level of local governments in Slovakia. In formulating this strategy, the city drew inspiration from other EU metropolises that have adopted similar approaches, recognizing the significance of such initiatives for a city with a population exceeding 500,000.

This strategy aims to establish a comprehensive understanding of the prevailing status quo in the circular and waste economy, to determine the optimal direction for development, and to allocate resources towards projects that are likely to yield the desired outcomes (MIRRI SR. 2023). In addition to the continuous monitoring and accurate recording of waste production in these containers, the sensor data will be used to optimize collection through

automatically created routes. These routes will take into account the shortest possible route and maximum utilization of vehicle capacity when returning to the depot. This approach has the potential to significantly reduce fuel consumption and, consequently, the emissions produced by collection vehicles. To facilitate comprehension, a simplified example of an optimal route is provided in Figure 6.24, which includes information regarding the fullness of waste containers.


Figure 6.24

Smart waste collection in Bratislava

Source: Spiegel, 2021

*Sensoneo*, the company responsible for this intelligent waste collection solution, has developed a system that utilizes advanced technology to address these challenges. Another solution in waste management is the Watchdog tool, which completely digitizes waste collection. This apparatus is designed to record all activities related to waste collection and collection. Consequently, the system is capable of identifying unmarked containers and

updating the container database as per real data. Furthermore, it records vehicle routes and offers a multitude of additional functions. The tool is composed of a central *Watchdog unit*, which is installed directly on the collection vehicle and utilizes antennas to identify containers (Spiegel, 2021). A number of additional projects are underway in Bratislava, including the construction of *Reuse centers*. These facilities, designated as "COPs," serve as collection points where residents can donate functional items that are no longer needed. In addition, these centers facilitate the exchange of secondhand goods among residents, fostering a sense of community and sustainability. In the Slovak Republic, there are currently two centers: one community center in Trnava and one city center in Bratislava. *Baterkáreň* - Battery Factory is the inaugural community reuse center to be operated by the civic association Sa Uvedom. Battery Factory is an organization that engages in a variety of initiatives, including the collection of secondhand items throughout the year, the facilitation of clothing SWAPs, the operation of a packaging-free store, and the provision of a community center that hosts various educational activities. The Bratislava Reuse Center, otherwise known as *KOLO*, was inaugurated in October 2022 by the collection company OLO in collaboration with the capital. KOLO also includes the HUB of Ideas and Ideas — an educational and creative center for people from Bratislava and the surrounding area. Furthermore, it engages in collaborative efforts with non-profit organizations, aiming to assist and empower individuals from disadvantaged and marginalized groups within the population (Porubský, 2021; Lin et al., 2022).

A waste recovery processing plant has been established in the city of *Žiar nad Hronom*. This facility, known as the Waste Recovery Center, consists of four separate and technologically interconnected facilities. These facilities include a sorting facility for separated municipal waste components,

a mechanical treatment facility for non-hazardous waste, an energy recovery facility for bioactive waste, a fermentation and biogas station, and a gasification facility. The facility is currently operating at a rate of up to 2,000 tons of municipal waste per year. The infrastructure is currently in a trial operational phase, and its capacity is designed to meet the needs of the city and the surrounding region when fully operational. The primary function of gasification is the generation of heat, which is intended for the heating of municipal buildings, and electricity, which will be reinjected into the grid, with the revenue utilized to fund operational expenses. Subsequently, a mechanical treatment facility receives the mixed municipal waste, from which the biological fraction and dry commodities are extracted and subsequently returned to the process in the center. In September 2017, a trial operation was initiated involving the collection and processing of biodegradable kitchen waste from households in a biogas station. In 2019, the city initiated a pilot program involving the installation of sensors to monitor the capacity of waste collection containers. The expected outcomes of this initiative include the optimization of collection routes and frequencies, the collection of data on the ratios of sorted components and municipal waste at individual stands, and the establishment of a comprehensive monitoring system for effective waste management. This will enable the local government to address individual stands in a targeted manner, thereby contributing to the enhancement of the city's overall waste management efficiency (Ministry of Environment of the Slovak Republic, 2019).

The city of *Trnava* is a notable Slovak pioneer in the domain of smart technologies for waste management. As part of the Smart City concept, the city of Trnava has introduced a waste container monitoring system that utilizes sensors to assess the fullness of the containers in real time. This data is then transmitted to a central system that facilitates the optimization of

collection vehicle routes, thereby reducing transport costs, emissions, and traffic congestion. Sensors were installed on containers for both separated and municipal waste. This allowed for more precise prediction of collection needs and prevented overflowing containers. This system has been demonstrated to enhance recycling rates and facilitate more effective waste sorting among residents. The case of Trnava demonstrates that the implementation of smart technologies can enhance the efficiency of waste management, alleviate environmental concerns, and promote the sustainability of urban processes.

This initiative represents a significant stride towards a more contemporary and environmentally sustainable Slovakia (City of Trnava, 2021a). Since 2021, the city of Trnava has been utilizing the contemporary "Moje Smeti" system to digitally monitor waste collection in the city districts of Špiglsál, Tulipán, Modranka, Kopánka, Vozovka, Vajslova, and the central district. At present, the vast majority of waste bins in these locations—more than 90%, in fact—are equipped with RFID chips. As of December 1, 2021, a total of 18,958 containers had been marked in Trnava. The system is designed to monitor and evaluate the frequency and quantity of waste removal. The automated documentation of waste removal is facilitated by RFID chips embedded in containers and dedicated antennas installed on collection vehicles. The system meticulously records the volume and weight of waste as per the unique number assigned to each container. The objective of introducing the Moje Smeti service is as follows (City of Trnava, 2021b; FCC Slovakia, 2022):

- Improving the efficiency of waste management from an ecological point of view.
- Collect data to optimize waste collection costs.

- Reducing the volume of municipal waste produced through separation.
- Eliminate price increases for municipal waste disposal, as well as increasing citizens' own costs for waste collection.
- Increase the amount of material and energy-usable components of waste.
- Reduce the amount of waste disposed of in landfills.

*Košice*, the second largest city in Slovakia, is also implementing various elements of the Smart City concept in the field of waste management. These initiatives include the implementation of sensor-based monitoring systems for waste containers and the integration of an intelligent waste sorting system.

This system utilizes sensors to ascertain the level of fullness of containers, thereby facilitating the optimization of waste collection. Moreover, the initiative encompasses the establishment of educational platforms for city residents, with the objective of enhancing awareness regarding proper waste sorting methods. Košice places a particular emphasis on fostering innovations in the domain of recycling, with the dual objectives of ensuring effective waste management and catalyzing the development of green technologies. This initiative has been designed to enhance the quality of life for residents by facilitating enhanced accessibility to public services and contributing to environmental protection.

The city of *Nitra* has implemented a digital waste management system that facilitates more efficient monitoring, sorting, and collection of waste. This project utilizes contemporary Internet of Things (IoT) technologies to oversee the condition of waste containers, thereby reducing waste collection expenditures and enhancing the efficiency of the collection process.

Moreover, the system facilitates the recycling of organic waste, thereby exerting a beneficial effect on the environment and contributing to the

reduction of greenhouse gas emissions. As part of this initiative, a mobile application was developed to facilitate the monitoring of container fill levels by city residents, manage their orders, and enable their participation in the waste sorting process. This project also includes innovations in the field of waste management that contribute to better use of materials and reducing the volume of waste in landfills (MIRRI SR, 2022).

In the city of *Senec*, a 40% reduction in the generation of mixed municipal waste was achieved over a period of four years. This phenomenon persists despite the observed growth in the population. City officials attribute the success primarily to the implementation of an electronic registration system for containers and a novel approach to incentivizing waste sorting.

Figure 6.25
The process of RFID tagging refuse containers
Source: GX SOLUTIONS (2025)

The implementation of a digital coding system for containers allocated to individual households has been identified as a pivotal strategy for enhancing the efficacy of waste management practices. This approach enables both local governments and waste collection companies to obtain

precise data concerning waste generation within households (Motúzová, Potočár, 2022). As illustrated in Figure 6.25, GX SOLUTIONS is the supplier of various solutions in motivating examples.

The municipality of *Košeca*, located in proximity to Ilava, has initiated a contemporary and pioneering initiative to establish a smart waste management system. The initiative employs a contemporary, pioneering SMART project centered on waste registration. The residents of this area incur expenses solely for waste that is not identifiable or cannot be sorted, and which could potentially be disposed of in a landfill. The municipality of Košeca has instituted an electronic waste registration system, whereby each family has been provided with bags bearing unique QR codes. As illustrated in Figure 6.26, these bags are subsequently deposited into containers equipped with electronic chips. Subsequently, the QR codes and electronic chips are scanned by public administration employees who collect these bags. The municipality of Košeca employs an electronic municipal waste registration system to monitor household waste production and to determine the methods of waste separation employed by residents (MIRRI SR, 2022b).


Figure 6.26

Example of container registration using QR codes

Source: MIRRI SR, 2022b.

The city of *Hlohovec* uses the aforementioned solution for intelligent waste management, produced by the Slovak company Sensoneo, as per waste monitoring with ultrasonic sensors and sophisticated software, which ultimately allows waste to be weighed according to real needs. Currently, sensors are installed in a total of 93 glass containers and in semi-underground containers. By introducing the application, the city is monitoring the efficiency of glass exports. Using the Sensoneo mobile application, the public can also help monitor the level of container filling in our city. The application allows residents to see and use data from Sensoneo sensors that monitor waste in containers, see Figure 6.27 (City of Hlohovec. 2022).


Figure 6.27
Smart waste management in Hlohovec
Sourece: The city of Hlohovec, 2022.

The established Sensoneo technology offers a novel instrument, WatchDog, which facilitates the digital transformation of waste collection processes. According to the creators of the tool, its utilization enables the comprehensive digitization of the collection process in its entirety, thereby ensuring the transparency of waste flows. Consequently, it enables cities and municipalities to implement straightforward quantitative collection models, such as "Pay-as-you-throw."

The adoption of these solutions has enabled Sensoneo to educate its clientele, irrespective of geographical location, on the pressing challenges they currently face. The transparency of waste flows and the efficiency of the waste collection process have been identified as critical factors. WatchDog is a solution for digitizing the collection process. The hardware solution is comprised of multiple components. The technology is predicated on a central unit, a device measuring 10 x 8 x 20 cm that is installed directly on the vehicle. The solution also includes four adjustable RFID UHF antennas, two of which are used to identify containers authorized for collection and two to confirm dumping. Antennas are typically positioned on the upper and lateral components of the vehicle. Containers or bags are marked with tags (RFID UHF labels or stickers), which facilitate communication with vehicles. The Slovak company Sensoneo has developed the WatchDog tool, which is designed to meticulously and automatically document all activities conducted during waste collection. WatchDog is a smart solution that enables municipalities and waste collection companies to maintain their current waste collection practices while providing them with an accurate overview of collected containers or bags. This smart solution has the capacity to identify unpaid or problematic containers, update the container inventory according to real data, and accurately record all routes taken. The technology also includes comprehensive fleet management. WatchDog is a solution for the digital transformation of the collection process. The hardware of the solution is comprised of several components. The technology is predicated on a central unit, a device measuring 10 x 8 x 20 cm that is installed directly on the vehicle. The solution also includes four adjustable RFID UHF antennas, two of which are used to identify containers authorized for collection and two to confirm dumping. The antennas are typically positioned on the vehicle's top and sides, while the tags (RFID UHF labels or stickers) serve to identify

containers or bags, facilitating communication with the vehicles. The system is activated by starting the vehicle. During collection, WatchDog automatically records all actions performed and stores them in the Sensoneo modules for infrastructure management (Asset Management), collection management (Route Planning), and vehicle management (Fleet Management). The Fleet Management module facilitates the execution of daily tasks pertaining to vehicles and routes. Operators are granted an overview of all activities carried out in the field and in the depot, including their current status, cost overview, and the ability to update collection routes for drivers in real time and vehicle localization on the map (Potočár, 2021; Sensoneo, 2024).

### 6.2.3 Comparison of approaches and results in Slovakia and other EU countries

**1. Slovakia vs. Netherlands (Amsterdam).**

A comparison of Slovakia and the Netherlands reveals that the former is in the early stages of implementing smart solutions for waste management, whereas the latter is a leader in this field. While sensor systems for waste monitoring and optimization of collection routes are already commonplace in Amsterdam, these technologies are gradually being introduced in Slovak cities such as Bratislava and Košice. Slovak cities continue to grapple with the necessity of increased investments in modern technologies, in addition to technological impediments that hinder the implementation of these systems.

**2. Slovakia vs. Germany (Hamburg).**

A comparison of Slovakia and Germany reveals a notable disparity in the utilization of Waste-to-Energy technology. While Germany has already incorporated this technology into its energy sustainability strategy, Slovakia has yet to do so. Instead, Slovakia is primarily focused on enhancing its waste

sorting and basic waste collection technologies. In Germany, an integrated system of waste collection and processing for energy recovery has been implemented, contributing to a reduction in the volume of waste disposed of in landfills. The Republic of Slovakia stands to benefit from the experience of the Federal Republic of Germany in the domain of waste-to-energy, thereby effecting a reduction in the environmental burden and an augmentation of the share of renewable energy sources.

**3. Slovakia vs. Austria (Vienna).**

The city of Vienna has demonstrated notable leadership in the realm of waste management, adopting a strategy that aligns with the principles of the circular economy. The city has implemented recycling technologies and waste reduction strategies in accordance with its objective of achieving zero waste by 2030. In Slovakia, despite ongoing initiatives to enhance recycling and waste management, the integration of digital platforms and intelligent solutions remains imperative, as evidenced by the case in Vienna. Slovakia stands to benefit from Vienna's experience in increasing recycling rates and enhancing waste management efficiency through technological innovations.

**4. Slovakia vs. France (Lyon).**

Lyon serves as a prime example of a city that has effectively integrated smart technologies into its waste management infrastructure, primarily through the implementation of sensors and real-time waste tracking systems. In the Slovak Republic, the implementation of these technologies remains in its nascent stages. Cities such as Bratislava and Košice have initiated the implementation of smart waste collection systems; however, they continue to encounter technological and financial challenges. While Lyon has already adopted advanced analytics to enhance waste collection and boost recycling rates, Slovak cities are in the nascent stages of implementing these technological innovations.

**5. Slovakia vs. Norway (Oslo).**

Oslo has established itself as a global leader in the realm of energy utilization from waste and biogas. In contrast, Slovakia has seen a comparatively limited implementation of these technologies, largely due to legal and legislative constraints that impede the adoption of Waste-to-Energy technology. While Oslo utilizes organic waste as a source of energy, Slovakia still possesses substantial reserves in this sector. This approach stands to benefit Slovakia, particularly in light of the mounting imperative to augment the share of renewable energy sources (MIRRI SR, 2023; European Commission, 2025; Ministry of Environment of the Slovak Republic, 2019; ICLEI Europe, 2025).

## 6.3 Challenges, suggestions and recommendations for improving Smart City in the area of waste management and circular economy

The implementation of Smart City elements in the field of waste management in Slovakia faces several challenges but also benefits and advantages. A primary benefit of intelligent waste management is the enhancement of waste collection efficiency. Sensors that monitor the fullness of containers allow for the optimization of collection routes, thereby reducing operating costs and the carbon footprint. Another benefit of the program is the support of separate collection, which has been shown to increase the recycling rate and reduce the volume of waste sent to landfills. Consequently, the financial burden associated with waste processing is mitigated, thereby providing residents with tangible financial relief. Furthermore, the implementation of smart systems in municipal settings facilitates the

provision of detailed waste data, thereby enabling the optimization of strategic decision-making processes and the implementation of targeted problem-solving methodologies. For instance, the capacity to identify locales exhibiting inadequate waste sorting facilitates the implementation of targeted awareness initiatives.

The implementation of energy-efficient technologies, such as biogas plants or gasification, facilitates the conversion of waste into an energy source, thereby reducing reliance on fossil fuels. The implementation of effective waste management strategies in Smart Cities has been demonstrated to offer significant benefits in terms of efficiency, environmental protection, and quality of life. First, the economic, social, and environmental benefits of the Smart City waste management concept for Slovakia will be described.

1. *Economic benefits:*

The implementation of Smart City solutions in the domain of waste management has been demonstrated to engender substantial economic benefits, particularly in the form of operating cost savings. Intelligent waste collection systems that employ sensors to monitor the fullness of containers have been shown to optimize routes and reduce the need for inefficient collection. This approach has been demonstrated to result in significant cost savings, including reduced fuel expenses, labor costs, and operational costs for collection services. Furthermore, the implementation of more efficient waste sorting and recycling processes has been demonstrated to result in a reduction of expenditures related to the storage of waste in landfills, as well as the treatment of waste. This approach has also been demonstrated to engender an increase in the level of competition. Furthermore, the implementation of more efficient waste sorting and recycling processes has been demonstrated to result in a reduction of expenditures related to the storage of waste in landfills, as well as the treatment of waste. This approach

has the additional benefit of increasing the competitiveness of cities, as it reduces waste management costs and supports sustainable business.

*2. Social benefits:*

The implementation of Smart City solutions has been demonstrated to engender a number of social benefits, including the enhancement of the quality of life for residents, the augmentation of citizen participation in environmental decision-making processes, and the promotion of greater transparency in the management of city services. The enhancement of urban infrastructure and the digitization of public services have been identified as key factors in fostering social inclusion, as they facilitate greater accessibility for all residents, irrespective of their demographic or economic background. This initiative facilitates enhanced access to information regarding recycling and other environmental initiatives, thereby fostering a sense of community responsibility.

*3. Environmental benefits.*

Among the most significant environmental benefits are the reduction of waste sent to landfills and the increase in recycling rates. Many cities that implement smart waste management solutions have seen an increase in the share of recycled materials, which reduces the burden on natural resources and the negative impact of waste on the environment. The principles of the circular economy—namely, the reduction, reuse, and recycling of materials—are instrumental in facilitating the efficient management of waste, thereby contributing to the pursuit of sustainable development. This approach offers several environmental benefits, including the reduction of space requirements in landfills, a decrease in CO2 emissions from packaging materials, and an enhancement in the energy efficiency of urban systems.

Regarding *barriers*, the implementation of smart waste management solutions is often hindered by the necessity of a substantial initial investment.

The construction of contemporary collection points, sensor systems, and processing facilities can impose substantial financial obligations that many municipalities may find challenging to meet. This phenomenon is also related to the lack of technical capacity and expertise to ensure the implementation and maintenance of these systems. Another barrier pertains to the insufficient awareness and motivation of residents. The implementation of intelligent solutions necessitates the active collaboration of citizens, a collaboration that is often predicated on the dissemination of educational materials and the modification of entrenched practices. The efficacy of intelligent measures is contingent upon adequate participation, which in turn is influenced by various factors. The presence of inadequate infrastructure for the management of particular waste categories, including electronic waste and toxic substances, has been identified as a salient concern. Conversely, the absence of consistent implementation of smart systems may result in the emergence of regional inequalities. The subsequent section will examine the technological, legislative, and financial *impediments that the implementation of the Smart City concept entails.*

*1. Technological barriers.*

Technological barriers are frequently linked to the necessity of ensuring compatibility among disparate systems. For cities implementing Smart City solutions, it is imperative to provide comprehensive, integrated solutions for waste management and monitoring. This can be a challenge, especially if cities use different platforms or devices to manage this information. A further challenge pertains to the assurance that these technologies can be effectively scaled up to larger cities or diverse urban areas.

*2. Legislative barriers.*

Legislative barriers may include the lack of uniform rules and regulations for the implementation of Smart City technologies in the field of

waste management. Numerous municipalities encounter challenges in assimilating disparate legislative frameworks and standards at both the national and local levels. Furthermore, legislative barriers may be present in the domain of data protection and personal information. The implementation of technological solutions for waste tracking in urban areas necessitates the consideration of legal implications concerning privacy and data security. It is imperative for these cities to ensure that the deployment of such systems does not contravene existing legislation pertaining to these matters.

*3. Financial barriers.*

The implementation of contemporary technologies necessitates preliminary expenditures to acquire and install the requisite infrastructure, in addition to developing the technology itself. This financial obligation can present a challenge for municipalities with constrained budgets. While the implementation of these solutions can result in future savings, the initial investment may require significant financial resources from municipal governments. Concurrently, smaller cities encounter challenges in securing sufficient financial resources to support these technological transitions, which can impede the progress of the Smart City development initiative.

The ensuing discussion will address the following aspects within the context of identified *problem areas and risks*. As demonstrated in the preceding chapter, the city of Bratislava does indeed have sensors installed on a limited number of waste containers. However, due to the minimal percentage of containers that are equipped with these sensors, it is not feasible to utilize the data generated from these sensors in a constructive manner. This is due to the fact that the impact of such utilization would be negligible in terms of improving the overall situation in Bratislava. Presently, sensors are exclusively installed in containers designated for sorted waste. Consequently, no technology-based solution has been implemented in

municipal waste collection, a domain in which substantial potential for enhancement exists. However, it is imperative to acknowledge the potential for sensor malfunction due to accumulation of debris, such as garbage, which can occlude the RFID chip. Another issue that may emerge when implementing Smart City elements in the domain of waste management is the so-called "*traveling salesman problem*." The traveling salesman problem is a well-known algorithmic problem. The objective is to find the shortest possible route between all points that need to be visited. To illustrate this concept, consider a salesperson tasked with visiting customers within a constrained timeframe, with each customer residing in a distinct city or district. The objective is to efficiently navigate all customers while minimizing travel expenditures. A particular instance of the TSP problem is the Vehicle Routing Problem (abbreviation VHP), which involves the consideration of road networks and traffic regulations and constraints. From a higher-level perspective, this solution also addresses the current traffic situation, as evidenced by the mobile applications Google Maps and Waze. In the context of waste collection, the algorithm for solving this problem can be used to optimize collection routes and reduce costs. The implementation of this problem into the collection plans of Bratislava is expected to yield a number of benefits, including a reduction in the number of kilometers traveled and the time spent on the road. This, in turn, will result in a decrease in the number of necessary collection vehicles, or, while maintaining the same number of vehicles, the ability to carry out waste collection faster and create space for better adaptation to a possible increased volume of waste produced, as is evidenced by the current trend. It is hereby proposed that the city of Bratislava implement the introduction of TSP for the optimization of collection routes in the form of a software tool into the information systems of collection companies (Wright, 2024). A survey of the current market

reveals the existence of analogous tools, which are available for purchase. Alternatively, it is possible to commission a custom-made tool for the specific purpose of waste collection. Concurrently, in relation to the preceding subchapter, this instrument should encompass capabilities for the implementation of dynamic waste collection.

*1. Problem areas in implementation.*

A significant challenge lies in the implementation of smart solutions in smaller cities and municipalities, which frequently lack the technical and financial capacity to undertake complex projects. Furthermore, cities may encounter coordination problems between different stakeholders, such as public and private entities, which can impair the effectiveness of the implementation of solutions.

*2. Risks*

The primary risks associated with the implementation of Smart City projects in the domain of waste management pertain to technological failures, which can result in suboptimal waste collection and the failure of optimized routes. Another risk is the absence of citizen involvement in waste management processes, which can reduce the effectiveness of the solutions. The city may also face the risk of data inaccuracy if sensors or systems are set up incorrectly or if there are problems with system integration.

In terms of opportunities for the development of Smart City and circular economy in Slovakia, there are following aspects:

- The Slovak Republic possesses considerable potential to leverage innovations and novel technologies, which have the capacity to profoundly transform the domain of waste management. The implementation of Internet technologies and sensors for waste monitoring has been demonstrated to improve the quality and efficiency of waste collection and recycling. Numerous local

governments and businesses have already initiated the development of novel technological solutions designed to assist in reducing waste and enhancing the efficiency of public services.

- It is imperative to educate the public on the significance of proper waste management and recycling. Educational initiatives targeting residents in regard to recycling processes have been demonstrated to facilitate an increase in recycling rates and a corresponding reduction in the volume of waste disposed of in landfills. Digital platforms and mobile applications have the potential to provide residents with tools to monitor waste behavior and participate in local programs.
- The success of Smart City projects is contingent upon effective collaboration among the public, private, and academic sectors. Municipalities that engage in collaborative partnerships with private enterprises and academic institutions stand to benefit from the implementation of novel technologies and research findings in urban development projects. These synergies facilitate the expeditious implementation of innovations and the initiation of sustainable development processes.

The following issues can be mentioned as part of the *recommendations for the further development of Smart City and circular economy in Slovakia.*

*1. Support and investment in smart technologies.*

To this end, Slovakia should prioritize the allocation of additional resources to the field of waste management innovations, with a particular emphasis on smart collection systems and Waste-to-Energy technologies. A central focus on IoT sensors, which facilitate enhanced monitoring of waste containers and the optimization of collection vehicle routing, has the potential to yield substantial cost savings and a reduction in CO2 emissions.

A potential benefit of this approach would be a reduction in the dependence on traditional energy sources, which would in turn improve energy sustainability.

*2. Legislative support and creation of uniform standards.*

In order to facilitate the development of Smart City solutions in the domain of waste management, it is imperative that national legislation establish consistent standards and provide support for the implementation of these technologies. To this end, Slovakia should prioritize the establishment of a legal framework that will enable the implementation of modern waste management solutions, with guidance from the most effective European practices. A comprehensive and coordinated approach between municipalities, private companies, and government institutions is imperative for the effective implementation of these measures.

*3. Raising public awareness and citizen involvement.*

A high level of citizen awareness regarding proper waste separation is a critical factor in enhancing recycling rates. The municipality has the capacity to establish digital platforms that empower citizens to manage and monitor their waste, while also engaging them in decision-making processes related to waste management. Empirical evidence from Barcelona and Copenhagen demonstrates the efficacy of mobile applications and public campaigns in enhancing citizen engagement and optimizing waste separation.

*4. Public-private-academic collaboration.*

The collaboration between the public, private, and academic sectors is of equal importance. Research and technology institutions have the potential to play a pivotal role in the development of innovations in waste management, which can subsequently be applied in urban settings. Collaboration with technology companies can guarantee access to the latest technologies, which can significantly improve the efficiency and sustainability of urban systems.

*5. Supporting the circular economy.*

To this end, Slovakia should consider allocating additional resources to the promotion of a circular economy, an approach that emphasizes the reuse of materials and the reduction of waste. In addition, it is imperative that the initiative supports recycling efforts to optimize the proportion of materials that can be repurposed in subsequent production processes. Green and sustainable initiatives must align with the overarching EU-wide objectives of reducing environmental burdens and promoting sustainable development (Shukla, Hait, 2022; Esmaeilian, et al., 2018).

In the chapter, we defined the Smart City concept, analyzed specific cities and their methods of implementing this concept, and although we cannot say that Slovakia is among the leading countries in implementation, we must conclude that it is necessary to devote more attention and efforts to this issue by all parties involved. The Slovak Republic is a country with exceptionally beautiful nature and cultural heritage. The Smart City concept could be a suitable means of protecting the country, particularly in the area of waste management, which has proven to be problematic. The following can be included among the selected identified inspiring examples for Slovakia.

*1. Amsterdam – Integration of Digital Platforms.*

Amsterdam serves as a noteworthy exemplary in the domain of leveraging digital platforms to enhance waste sorting and monitoring of waste containers. This approach can serve as a valuable model for Slovak cities, which may consider implementing analogous applications to inform residents and enhance their participation in waste management. The utilization of mobile applications has the potential to enhance communication between the municipality and its constituents, thereby fostering a greater awareness of available recycling stations.

*2. Hamburg – Waste-to-Energy technologies.*

The city of Hamburg has developed technologies that convert waste into energy. For the Slovak Republic, Hamburg's strategy for energy utilization from waste would serve as a valuable source of inspiration. The implementation of Waste-to-Energy (WtE) technologies would enable Slovakia to generate energy from waste, thereby reducing its reliance on traditional fossil fuels. This approach would have a positive impact on reducing CO2 emissions and would support the sustainable development of Slovak cities.

*3. Vienna – Educational programs to raise awareness.*

Vienna, a leader in zero waste initiatives, can serve as a source of inspiration for Slovak cities seeking to implement similar educational programs. The promotion of awareness regarding waste sorting and the role of citizens in the recycling process is imperative to enhance recycling rates in Slovakia. Such programs have the potential to enhance social inclusion and promote civic engagement in environmental protection.

*4. Lyon – Waste monitoring technology and citizen engagement.*

The utilization of advanced waste monitoring technology in conjunction with citizen engagement initiatives has emerged as a pivotal aspect of contemporary waste management strategies. Lyon serves as a source of inspiration for Slovakia in the domain of digital platforms and mobile applications for the purpose of monitoring waste management and citizen engagement. The city has developed a system that allows residents to monitor the status of containers and inform the city administration about places where intervention is needed. The Slovak Republic stands to benefit from the implementation of analogous applications that would assist in enhancing public awareness regarding proper waste sorting practices and facilitating enhanced communication between residents and the local

government. These platforms have the potential to facilitate social responsibility and active participation in environmental projects.

*5. Oslo – Waste-to-Energy and the Circular Economy.*

The city of Oslo has implemented a waste-to-energy program and a circular economy initiative. Oslo serves as a prime illustration of how organic waste can be utilized effectively to generate renewable energy. This approach has the potential to serve as a source of inspiration for Slovak cities, which may develop analogous biogas technologies for the purposes of waste treatment and energy production. The implementation of Waste-to-Energy (WtE) technology in Slovak cities could contribute to reducing the environmental burden and, concomitantly, increase the energy independence of cities.

Furthermore, this approach has the potential to bolster Slovak initiatives aimed at decarbonization and the reduction of CO2 emissions.

A comprehensive review of the aforementioned issues has yielded the following set of recommendations concerning the domains of waste management and the circular economy within the paradigm of Smart Cities:

1. The introduction of smart sensors in containers is a significant development in the field of maritime automation. A pivotal step in this process entails the integration of sensors within waste containers, thereby facilitating the continuous monitoring of their capacity. These sensors facilitate the real-time monitoring of container status and the optimization of waste collection schedules.

The utilization of this approach has the potential to:

- minimize the frequency of collection trips, thereby reducing carbon dioxide emissions.
- minimize both the transportation and maintenance costs associated with vehicles.

- enhance the level of cleanliness and aesthetic appeal of public spaces.

2. The utilization of software solutions in the domain of route planning is a subject that merits attention. Sensory data can be integrated into software systems to facilitate dynamic route planning for waste collection. The functionality of such systems can be categorized as follows:

- to optimize routes with the objective of minimizing distances and collection times.
- to consider the prevailing traffic conditions, including but not limited to, road closures and fluctuations in traffic density.
- to empower operators with autonomy to manually adjust routes in accordance with specific requirements, such as seasonal or one-time collections.

3. The notion of supporting the circular economy through the utilization of digital platforms is a subject that merits further examination. Digital platforms have the potential to enhance the recycling and reuse of waste materials. The following recommendations are provided:

- to create applications through which residents can accrue rewards for the proper sorting of waste is a concept that merits further consideration.
- to establish a network that facilitates the exchange of recycled materials between local businesses and municipal collection centers.
- to raise public awareness through the implementation of educational campaigns that emphasize the significance of recycling.

4. The implementation of waste-to-energy systems is a critical component of sustainable energy development. Smart technologies have the potential to enhance the functionality of contemporary waste incinerators,

which are facilities that convert waste into energy. Facilities of this nature have the capacity to:

- to generate heat and electricity for residential and commercial properties is a primary objective.
- to reduce the volume of waste that is disposed of in landfills.
- to utilize the by-products, including ash and scrap, for additional processing is a crucial aspect of promoting a circular economy.

5. Monitoring and analytics through the Internet of Things (IoT) and big data: To that end, metropolitan areas would be well-advised to allocate resources toward the implementation of systems capable of collecting and analyzing data concerning waste management. The functionality of such systems can be categorized as follows:

- to identify areas with low recycling rates and propose effective solutions to enhance these rates.
- to employ a forward-thinking approach to forecast future trends in waste production and subsequently adjust management plans.
- to implement methodologies that facilitate the precise monitoring of the ecological ramifications associated with the management of waste.

6. Support of the utilization of decentralized solutions: Municipalities have the capacity to provide support for local initiatives, such as community composting sites or small recycling stations. Smart technologies have the potential to:

- to meticulously monitor the quality of compost and ensure the efficient decomposition process.
- to establish a nexus between these initiatives and the city's waste management system to ensure optimal coordination.

## 6.4 Summary

In this chapter, we concentrate on the analysis of the implementation of Smart City elements in the field of waste management, focusing on examples of successful projects in Slovakia and the EU. A study of the Smart City concept in Slovakia reveals that, despite its gradual development, the concept faces several challenges. These challenges include technological, financial, and legislative barriers that affect the speed of implementation of advanced solutions. Nevertheless, initiatives in the field of smart waste collection, the use of sensors, and the optimization of collection vehicle routing are emerging in Slovak cities such as Bratislava, Košice, and Nitra. An analysis of examples from other EU countries, including Barcelona, Copenhagen, Lyon, Hamburg, and Oslo, indicates that EU cities are more advanced in terms of integrating technologies into waste management. These cities have adopted advanced solutions for the management of solid waste. These solutions include the implementation of the Internet of Things (IoT) sensors for the monitoring of waste, the integration of smart waste collection platforms, and the utilization of Waste-to-Energy (WtE) technologies for the reduction of waste and the production of renewable energy. As evidenced by case studies in Barcelona and Copenhagen, the utilization of technology to enhance waste collection and reduce CO2 emissions is imperative. This approach has been demonstrated to positively impact the quality of life for residents and the environment. Among European cities, Prague and Madrid exemplify the potential for digital transformation and automation to enhance waste management. Madrid, a leader in smart waste monitoring, deploys a vast array of sensors and sophisticated software solutions to minimize traffic congestion and enhance efficiency. Vienna, with its Spittelau incinerator, serves as a prime example of how waste can be transformed into a source of energy for tens of thousands of households.

This approach aligns with the principles of the circular economy, promoting the reuse and recycling of materials while minimizing environmental impact. A common denominator among these cities is their emphasis on the use of technology, with the objective of reducing emissions and transitioning to a circular economy. These initiatives have been shown to enhance the efficiency of waste management systems and contribute to the enhancement of the quality of life for residents while also playing a role in environmental protection.

The Slovak Republic is currently implementing ambitious plans to transition to a smart circular economy, which requires efficient waste management, recycling, and reuse of materials. Initiatives such as the Waste Management Program for 2021–2025 and the Environment Strategy 2030 are creating a legislative framework that aims to increase recycling rates and minimize negative environmental impacts. These measures are imperative for the realization of the EU's environmental objectives. However, the implementation process confronts numerous challenges, including the substantial costs associated with infrastructure modernization and the absence of public awareness. Despite the recent advancements in Slovakia's waste management, numerous practical and legislative impediments impede the transition to a circular model. The implementation of these plans is being hindered by several factors, including the financing of necessary infrastructure, the complexity of permitting processes, and the low levels of public engagement. A successful transition hinges upon effective public-private collaboration, as well as the implementation of innovative technological solutions that enhance the efficiency of recycling and waste management. Innovations such as new recycling processes and waste-to-energy can help Slovakia achieve a substantial reduction in landfill waste and enhance energy self-sufficiency. Furthermore, investments in research and

development of novel materials, such as bioplastics, engender new possibilities that must be judiciously implemented to avert deleterious impacts on conventional recycling processes. It is imperative for Slovakia to utilize these exemplars as a source of inspiration and to continue augmenting investments in innovation and public education. With the backing of European funds, state-of-the-art technologies, and collaboration at both the local and international levels, Slovak cities can achieve substantial progress on the road to a more sustainable and intelligent waste management system. Consequently, Smart Cities can function not only as a vision of the future, but also as a tangible response to present challenges.

# CHAPTER 7. SMART ENERGY CITY POLICY CONCEPT - IN BALANCE WITH THE PLANET

Smart City energy policy constitutes a pivotal component of the overarching concept of Smart Cities, a response to the escalating energy demands of contemporary urban areas. The policy's primary objective is the efficient utilization of available energy resources, with a secondary objective of reducing environmental burdens and supporting technological innovations that can contribute to improving the quality of life of residents. In the context of mounting urbanization and mounting pressure for sustainable development, there is an imperative to integrate advanced technologies and adopt novel approaches to energy resource management. Smart City energy policy, therefore, is a comprehensive framework that integrates modern technologies, environmental strategies, and socio-economic objectives. The Smart City energy concept is predicated on the utilization of contemporary technologies and innovations for the efficient and sustainable management of energy resources in urban areas. The objective of this initiative is to enhance energy efficiency, mitigate greenhouse gas emissions, and enhance the quality of life for residents through the implementation of intelligent energy systems. These systems include smart grids, renewable energy sources, and energy-efficient building practices. These initiatives enable cities to achieve multiple objectives, including energy savings, adaptation to climate change, cost reduction, and the promotion of ecological and economic sustainability. The implementation of these policies necessitates collaboration between the public and private sectors, thereby contributing to the enhancement of the quality of life within urban environments. The objective of this chapter is to examine the potential of the Smart City concept in the energy sector to

enhance the quality of life in Slovakia, with a focus on socio-economic dimensions. The chapter's objective is to identify planned implementations and current projects, their benefits, limits, and barriers. A particular emphasis will be placed on the analysis of the opportunities presented by EU programs, as well as the insights derived from successfully implemented projects within Europe. Consequently, the subsequent presentation of proposals and recommendations will serve as the foundation for advancing the implementation of Smart City policies in the energy sector within Slovakia. This initiative will be informed by the particularities of our nation and will draw inspiration from the success of EU-level initiatives.

## 7.1 Definition and components of the Smart City policy concept in the field of energy

Within the domain of energy, the concept of a "*Smart City*" encompasses a series of integrated "*smart*" or intelligent solutions. For instance, the systematic monitoring of consumption and heat leaks in buildings can contribute to enhancing the energy efficiency of cities. Smart lighting has the potential to enhance energy efficiency in street lighting, reducing wasteful energy consumption during periods of non-usage. A comprehensive, universally applicable methodology for the transformation of urban entities into "Smart Cities" is not currently available. Given the unique characteristics of each city, the optimal approach entails the implementation of a customized combination of measures, each of which is selected to address the specific challenges and objectives of the city in question. The potential for implementing smart solutions in energy, transportation, waste management, and other areas varies from city to city. Smart City energy policy is centered on the implementation of contemporary technologies and methodologies that facilitate the effective utilization of available energy resources and optimize

energy consumption within urban environments. This concept is predicated on the integration of technologies such as the *Internet of Things (IoT)*, smart meters, and renewable energy sources. Collectively, these technologies contribute to enhancing efficiency and reducing the negative impact on the environment. The utilization of IoT devices constitutes a pivotal component of this policy. These devices, including smart thermostats and sensors, facilitate the acquisition of precise energy consumption data in real time, both by cities and individuals. For instance, the implementation of intelligent lighting systems within a specific urban district has the potential to autonomously modulate its luminosity in accordance with the presence of individuals or the prevailing time of day. This approach has the capacity to result in substantial energy savings. Concurrently, smart meters—frequently installed in residential buildings-offer comprehensive energy consumption analyses, empowering users to optimize their energy utilization and identify areas conducive to efficiency enhancement. Moreover, two-way energy networks facilitate decentralized energy trading between individuals and energy providers. Consequently, residents who generate their own energy, for instance through photovoltaic systems, can reduce expenses or even generate revenue by selling excess energy to the grid. This model has been implemented in various countries, including Germany and Denmark, where the decentralization of energy has played a significant role in driving substantial innovation. The significance of these components extends beyond mere technological advancement; their capacity to enhance the socio-economic conditions of residents is also a crucial factor. These measures have been shown to have a substantial impact on enhancing the quality of life. This is due to their capacity to facilitate the accessibility of sustainable energy sources, reduce energy expenditures, and promote sustainable urban development (MIRRI SR, 2022; Euractiv, 2011; Rojko, 2020).

The concept of a "Smart City in energy" refers *to intelligent management and optimization of energy systems* through the utilization of modern technologies. The fundamental components of this concept encompass the following:

1. *Intelligent energy networks, so-called Smart Grid*
    - Decentralized two-way energy flow between the producer, distribution networks and consumers.
    - Digitalization and automation of distribution network management to increase stability and flexibility.
    - Integration of renewable energy sources and management of fluctuations in production.
    - Use of the Internet of Things (IoT - in informatics, a term for connecting devices/objects/people to the Internet), sensors and big data analysis for monitoring and optimizing energy flows.
2. *Energy efficiency and sustainability*
    - Reducing the energy intensity of buildings using intelligent management and automation systems.
    - Use of renewable and emission-free energy sources in cities
    - Modernization and optimization of public lighting, heating, cooling systems, etc.
    - Reducing losses in energy networks and overall energy consumption in the city.
3. *Citizen involvement and transparency*
    - Providing citizens with clear information on energy consumption and environmental impacts.
    - Involving the public in planning and decision-making on energy projects.
    - Supporting the decentralization of energy sources and

community energy (European Commission, 2025d; MIRRI SR, 2022b).

The concept of "smart energy" is predicated on one or more of the principles of smart energy production, smart energy networks, smart energy storage, smart energy consumption, clean energy, green energy, sustainable energy, and renewable energy sources, in conjunction with information and communication technologies. A smart energy system is defined by the intelligent integration of decentralized sustainable energy sources, efficient distribution, and optimized energy consumption. Smart energy, therefore, is comprised of three distinct components that must be integrated and communicate effectively with each other to establish a cohesive smart energy system. According to Mohanty, Choppali, and Kougianos (2016), smart energy can then include:

- green energy,
- photovoltaic energy,
- solar thermal energy,
- biogas,
- wind energy.

The effective distribution of energy within this system is primarily facilitated by the implementation of smart infrastructure, smart grids, smart meters, and the integration of suitable levels of information and communication technologies (ICT). The core of a smart energy system is the information infrastructure that deals with the collection of energy consumption information and the sharing of information on the provider's rate. ICT is then employed to oversee operations, ensuring that energy consumption for smart appliances, such as dishwashers, is maintained at the optimal level. ICT has also been demonstrated to facilitate transactions for plug-in electric vehicles (PEV) and heating, ventilation, and air conditioning

(HVAC), thereby enabling the efficient utilization of energy purchased from diverse sources, including solar panel systems, wind turbines, and other potential energy sources. An essential component of a sophisticated energy system is optimized system consumption, which encompasses efficient energy storage, smart metering, and efficient energy management. This optimization of energy consumption in a smart energy system is paramount. According to Mohanty, Choppali, and Kougianos (2016) the foundation of a sophisticated energy system is a smart energy grid that integrates the actions and behaviors of all connected users:

- consumers,
- generators,
- users who are both consumers and generators.

The integration of a smart grid facilitates the establishment of energy systems that are characterized by efficiency, economic viability, and sustainability, accompanied by minimal losses. These systems are distinguished by an enhanced quality of supply, augmented system and user safety, and the capacity to withstand system disturbances. A smart grid facilitates the integration of diverse energy sources, including thermal energy, which is derived from fossil fuels, as well as green photovoltaic and wind energy. In the future, the smart energy grid is expected to be much more complex than it is today.

The subject of the smart grid is addressed by Wood (2023), who asserts that the transportation of electricity over long distances is inefficient and that microgrids are both the solution and a potential solution. Until recently, the microgrid was primarily utilized by university campuses, hospital complexes, shopping centers, and neighborhoods worldwide. A *microgrid* is defined as a local, independent, and intelligent energy solution. A microgrid functions in conjunction with the central grid; however, in the event of a central power

outage, it is capable of supplying energy independently. A microgrid employs a diverse array of energy sources, including solar and wind energy, as well as thermal and other energy sources, in conjunction with generators. The installation of a rudimentary solar panel array on the roof of a structure, or the implementation of backup batteries, does not constitute the creation of a microgrid. With respect to the utilization of information and communication technologies, the following objectives are of particular significance, as outlined by Mohanty, Choppali, and Kougianos (2016):

- to support demand-driven energy management,
- to dispatch electricity generation for solar panels and wind turbines,
- to facilitate location-independent transaction services for PEVs,
- to strengthen relationships with consumers.

Additionally, Mohanty, Choppali, and Kougianos (2016) assert that a crucial component of a smart grid is the measurement of energy consumption. A smart meter is a device that meticulously records electricity consumption at predetermined time intervals and transmits this data to specialized monitoring and billing systems. This innovation enables precise and dependable usage measurement without the need for manual input or documentation. A sophisticated battery, composed of lithium-ion or fuel cells, can be an effective solution for energy storage, offering enhanced efficiency and longevity.

## 7.2 European Strategic Energy Technology Plan (SET Plan)

This is a pivotal step in facilitating the transition to a carbon-neutral energy system by developing low-carbon technologies in a rapid and cost-competitive manner. The SET Plan fosters collaboration among EU Member States, businesses, and research institutions by promoting the advancement

of new technologies and the reduction of their costs through coordinated national research initiatives. The Plan's efficacy is rooted in its capacity to orchestrate transnational research and innovation initiatives, with the overarching objective of fostering the development of low-carbon energy within the ambit of EU Member States and associated nations.

A pivotal aspect of the Plan's strategy entails the harmonization of national research and innovation programs with its overarching agenda, ensuring a cohesive and synergistic approach to achieving its objectives. The SET Plan activities are divided into *ten research and innovation actions*. These actions encompass the entire innovation chain, from research to market deployment, with a focus on financing and regulatory frameworks.

- integration of renewable technologies into energy systems,
- reduction of technology costs,
- new technologies and services for consumers,
- resilience and security of energy systems,
- new materials and technologies for buildings,
- energy efficiency in industry,
- competitiveness in the global battery and e-mobility sector,
- renewable fuels and bioenergy,
- carbon capture and storage,
- nuclear safety (European Commission, 2025f; MIRRI SR. 2022d).

The development of *energy-efficient urban infrastructure* represents a pivotal initiative in the pursuit of reducing energy consumption in Smart Cities. The design of these buildings prioritizes energy efficiency, aims to reduce energy consumption, and incorporates the generation of renewable energy on site. This encompasses the use of sustainable and locally sourced materials in construction, the integration of smart lighting systems with motion sensors and daylight harvesting technology, and the design of

windows and glazing systems that facilitate natural light entry, thereby minimizing heat gain or loss and reducing reliance on artificial lighting and ventilation. However, there are numerous additional sustainable building practices that contribute to the enhanced efficiency of buildings in Smart Cities.

The implementation of *intelligent street lighting systems* is an integral component of the Smart City concept, wherein these systems are designed to autonomously adjust to prevailing environmental conditions, thereby facilitating energy conservation and cost savings. The illumination is not constant, a feature that is intended to prevent light pollution and conserve energy. The intensity of these lights is adaptable, contingent on the movement of pedestrians or the arrival of vehicles. In the event of an emergency, the lights can be automatically amplified to enhance visibility. Furthermore, these smart lighting systems are powered by renewable energy sources, such as solar panels and wind turbines.

This reduces infrastructure costs and increases the sustainability of the energy economy in cities. The construction and operation of buildings are responsible for a substantial consumption of energy, particularly for the purposes of heating and cooling. This makes buildings a critical component of sustainability initiatives. In the United States, commercial buildings account for 35% of electricity consumption, excluding residential homes. Smart HVAC systems facilitate this process by employing sensors to collect real-time data, which is subsequently transmitted to a cloud platform for analysis. This enables energy suppliers to monitor consumption and optimize efficiency, thereby reducing costs and preventing waste. Furthermore, these systems possess the capability to discern issues such as excessive vibration or diminution in efficiency prior to their overt manifestation, thereby facilitating expeditious remediation. This approach has the potential to

generate long-term savings by reducing energy consumption and the financial burden of replacement costs. The systems also automatically adjust temperatures as per occupancy and room usage, with AI improving their performance over time (Energy-Floors, 2023).

Smart Cities advocate for the adoption of *electric vehicles (EVs)*, which have been shown to exhibit superior energy efficiency and reduced emissions compared to traditional gasoline-powered vehicles. Energy floors, which capture and convert the kinetic energy of steps and movement into electricity, have already found application in various urban settings. Presently, this technology is undergoing preparations for its implementation in electric vehicles. These mechanisms are designed to absorb the energy generated by friction between the tires of electric vehicles and the road. This energy is subsequently converted into electricity through piezoelectric or electromagnetic systems.

The electricity generated can be used to directly power the vehicle engine or be stored in the vehicle battery for later use (Energy Floors). Smart charging stations establish a data connection with the electric vehicles that utilize them. The station is also connected to a smart charging operator, and the entire system is connected to the cloud. This system enables the supervising individual to manage and limit the charging station's use remotely, thereby optimizing energy consumption. For instance, they have the capacity to facilitate charging during off-peak hours. Smart chargers have the additional benefit of reducing charging costs for electric vehicle drivers. In conjunction with the expansion of charging infrastructure, this initiative aims to enhance the accessibility and dependability of electric vehicle (EV) ownership. This system is a critical component of decarbonization initiatives.

*Digitization* is a pivotal component of EU policy, as it facilitates the more efficient management of urban systems and energy flows. The Digital

Decade Action Plan establishes the objective of augmenting digital infrastructure and fostering the development of novel technologies, including smart meters, IoT devices, and automated systems. Projects funded by Horizon Europe include the development of technologies for monitoring energy consumption and forecasting demand, allowing cities to better adapt their energy infrastructure. A pilot project has been initiated in Amsterdam that employs Internet of Things (IoT) technologies to monitor energy flows in urban buildings, resulting in consumption optimization and cost reduction (European Commission, 2025h).

## 7.3 Latest trends in urban energy self-sufficiency

According to the European Commission (2025a), *the prevailing trends in achieving energy self-sufficiency in urban areas* include decentralization, digitalization, integration of renewable energy sources, development of energy storage technologies, and active involvement of citizens and communities. The objective of these initiatives is to enhance urban energy autonomy, curtail reliance on fossil fuels, and mitigate environmental repercussions.

- **Energy efficiency and savings** = The utilization of renewable energy sources (RES) entails the implementation of solar panels, wind farms, and analogous renewable energy sources for the purpose of local energy production. Furthermore, it involves the establishment of community energy systems, wherein citizens engage in both energy production and consumption.
- **Energy self-sufficient buildings** = The introduction of intelligent control and automation systems to buildings is a key factor in achieving energy efficiency and savings. These systems serve to

reduce the energy intensity of buildings and utilize modern technologies to optimize energy consumption in urban areas. Examples of such technologies include LED lighting and intelligent heating and cooling control systems.

- **Energy storage** = The development of energy-autonomous buildings is predicated on the creation of mobile energy containers capable of independently supplying buildings with heat or cooling. These containers utilize passive solar energy to achieve buildings with zero or nearly zero energy consumption.
- **The process of energy storage entails** the implementation of two primary components: batteries and storage facilities. These facilities are utilized for the purpose of accumulating excess energy derived from renewable energy sources. Additionally, hydrogen plays a crucial role in this process, functioning as an energy accumulator.
- **Integrated energy solutions** = The integration of energy solutions entails the convergence of diverse technological modalities, encompassing renewable energy sources (RES), energy storage mechanisms, and consumption management systems, within intricate energy systems. The implementation of predictive data analysis and artificial intelligence facilitates the optimization of these complex systems.
- **Citizen and community engagement** = Citizen and community engagement is defined as the practice of electricity sharing between households and community energy projects. This concept is further characterized by the raising of awareness and the motivation of citizens to engage in behaviors that are conducive to sustainability.

## 7.4 Energy Smart City policy analysis and best practices overview in EU and Slovakia

The implementation of Smart City solutions in the field of energy has yielded several successful projects and initiatives in Slovakia and within the European Union. These projects illustrate the potential of integrating modern technologies and renewable energy sources to achieve reduction emissions, energy efficiency enhancement, and improved quality of life for residents. To enhance clarity, the following discussion will focus on examples from Slovakia and successful initiatives from the EU, emphasizing specific technologies, solutions, and results.

### 7.4.1 Best practices in the EU within the Energy Smart City policy area

The European Union has emerged as a frontrunner in the implementation of innovative projects that utilize modern technologies and renewable energy sources with the objective of enhancing the quality of life for its residents, reducing their carbon footprint, and promoting energy efficiency. These projects encompass a broad spectrum of solutions, including the establishment of positive energy districts, the implementation of smart grids, the integration of solar and wind systems, and the development of community energy systems. A critical component of these initiatives involves the integration of smart technologies that facilitate the optimization of energy consumption, the facilitation of flexible charging for electric vehicles, and the development of interactive energy maps. The most significant projects implemented include the creation of positive energy areas in the city of Amsterdam, the comprehensive use of renewable sources in Freiburg, as well as groundbreaking solutions for smart mobility and green energy in Vienna. These initiatives function as exemplary models for other

regions, demonstrating the potential of technological advancement and international collaboration to foster a sustainable future.

*Amsterdam*, located in the Netherlands, has been a leader in the implementation of smart energy solutions. The city has undertaken numerous innovative projects with the objective of enhancing the sustainability and efficiency of its energy system. The *ATELIER* project is one of the key initiatives in which Amsterdam is collaborating with Bilbao to establish *Positive Energy Districts (PEDs)*. These areas have been designed to produce more energy than they consume by integrating buildings with smart mobility and technologies. The initiative encompasses additional cities, including Bratislava, Budapest, Copenhagen, Krakow, Matosinhos, and Riga, where the solutions successfully implemented in the initial phase will be replicated. Another significant project is *City-zen*, which was implemented in the Nieuw-West district of Amsterdam. This initiative facilitated the connection of over 10,000 households to a smart grid, a system that enables real-time monitoring and management of energy consumption. This network is equipped with sensors and remote control at all voltage levels, which allows the distribution company *Alliander* (Alliander Sustainable Area Development) to effectively manage the load and voltage in the network (Van der Stoep, 2016). Amsterdam has also developed the Energy Atlas, an interactive tool that provides a detailed overview of energy consumption in different parts of the city. This initiative enables residents and businesses to access data regarding their energy consumption, thereby facilitating the identification of opportunities for the utilization of renewable energy sources, such as solar or wind power. This atlas is designed to facilitate the transition to a renewable energy system by increasing awareness and promoting energy efficiency (Mara de Pater, 2016). In the domain of electromobility, the city of Amsterdam has initiated the *Flexpower project*, which aims to enhance the

efficiency of electric vehicle charging. This system enables flexible charging, adapting to the current availability of energy in the network. Consequently, it reduces the load on the network and promotes the use of renewable energy sources. In 2009, this project was initiated with the installation of 3,000 photovoltaic panels on the roofs of buildings in the Zuidas district of the city. These panels generate a sufficient amount of energy to meet the consumption needs of 30,000 citizens employed within this urban area (ElaadNL, 2017). Experts conduct site visits to businesses within the city, meticulously examining their energy management systems and proposing measures to the proprietors with the objective of enhancing energy efficiency. In addition, they offer a curated selection of products in collaboration with renowned companies such as Phillips. *The West Orange project*, which aims at intelligent data collection, is supported by a modern ICT infrastructure. The application enables individuals to monitor their energy consumption in real time and to evaluate their energy management. It also recommends possible measures as per this evaluation. In the initial phase, 500 households participated in the project. The project was found to have led to a mean reduction in energy consumption of 14% per household. The project encompassed the development of a smart socket. This feature enables the user to monitor energy consumption and schedule the shutdown of the socket to conserve energy when it is not in use (Sanseverimo Riva, 2017).

*Freiburg im Breisgau*, Germany, has been recognized as a leading municipality in sustainable urban development and smart energy solutions. The city has committed to reducing greenhouse gas emissions by 60% by 2030 and achieving climate neutrality by 2035, with the reference year being 1992. A seminal project of this initiative is *DATEN:RAUM:FREIBURG*, an ambitious endeavor that aims to integrate disparate data sets from various sectors, including ecology, economy, and

society, into a unified infrastructure. This system enables various stakeholders, including citizens, businesses, scientific institutions, and the media, to access data. Concurrently, the city administration and political authorities are empowered to make informed decisions as per reliable data. The project underscores the concept of digital sovereignty, stipulating that the municipality retains ownership of the data and is bound by privacy principles. In the domain of energy efficiency, the new city hall in Freiburg, conceived as a zero-energy building, represents a significant accomplishment. The building's design incorporates hybrid modules on the roof for electricity and heat generation, complemented by vertical photovoltaic panels integrated into the facade that function as shading elements. Consequently, the edifice not only covers its own energy consumption, but also contributes to the city's energy grid. The city of Freiburg has implemented a series of financial incentives designed to encourage citizens to undertake energy-efficient renovations. These incentives are intended to promote the installation of measures such as improved thermal insulation in buildings, efficient heating and ventilation systems, and photovoltaic devices. These measures are complemented by advisory services, including free consultations, which motivate residents to reduce energy consumption and use renewable energy sources. As part of the "Smart Cities 2020" initiative, the city of Freiburg received a substantial financial allocation of approximately 8.3 million euros to implement the Connected Urban Data Architecture (CUDA) project. This initiative is founded on the principles of integrated and sustainable urban development, with the objective of enhancing the efficacy of municipal processes through the optimal utilization of data (Stadt Freiburg, 2020).

Among the smart initiatives to make *Copenhagen* an even smarter city are energy, transport, and building projects that aim to reduce carbon

emissions by 20% over a ten-year period (2005-2015). The city's commitment to sustainability is further reinforced by the country's 2050 Energy Strategy, which aims to transition completely to renewable energy sources by the year 2050 and achieve energy independence from non-renewable sources through the following measures: It is imperative to curtail oil, gas, and coal consumption by 33% between 2009 and 2020. The Danish government's strategic approach to energy production entails a substantial emphasis on wind energy, which is projected to account for approximately 40% of total electricity consumption in the future, complemented by biomass and biogas. Denmark's commitment to renewable energy is evident in its strategic deployment of wind turbines in coastal waters, complemented by substantial financial support for research and development in solar and wave energy. Additionally, the country's engagement in geothermal projects signifies a diversified approach to renewable energy development. The energy produced from biomass is poised to be the primary catalyst for the transition to alternative heating sources. The utilization of oil-fired boilers in all buildings has been prohibited since 2017. In an effort to ensure affordability for all Denmarks, a public service tax will be implemented on electricity and gas, while taxes on oil, gas, and coal will undergo a substantial increase, thereby rendering their use unattractive (Cavada, Hunt, Rogers, 2017).

*Vienna*, Austria, has gained international acclaim for its forward-thinking Smart City initiatives. These initiatives are designed to enhance the quality of life for the city's residents by implementing innovations in three primary areas: energy, mobility, and urban planning. A prominent project in this regard is *Seestadt Aspern*, which is located in Vienna's 22nd district. Constructed on the grounds of a decommissioned airport, this carbon-neutral district encompasses 240 hectares and is projected to house over 20,000

residents and generate the same number of employment opportunities by the year 2028. Seestadt Aspern functions as a laboratory for the Smart City concept, wherein innovative solutions in the domains of housing, social security, energy, and mobility are evaluated and implemented. The district's strategic location ensures seamless connectivity with the metro and railway networks, thereby promoting the utilization of public transportation. The district is characterized by the presence of an artificial lake, which is believed to contribute to the enhancement of the microclimate and the provision of recreational opportunities. The buildings in Aspern meet high energy efficiency standards. For example, the Liselotte Hansen-Schmidt educational campus has been designed as a zero-energy school, using solar, wind, and geothermal energy (Smartcityvpraxi.cz, 2015). In the domain of energy, Vienna is undertaking pioneering initiatives, including the utilization of heat from a wastewater treatment facility to provide heating to up to 106,000 households in an eco-friendly manner. The city has allocated a substantial sum of 1.2 billion euros to the development of renewable energy sources. This initiative encompasses the construction of new photovoltaic power plants, the installation of solar panels on public buildings, and the establishment of wind power plants. Moreover, the biogas plant in Simmering processes kitchen waste into gas for heating, with plans to double its output and provide heat for 900 households. The city is also allocating resources to the development of a network of charging stations for electric vehicles, with the objective of increasing their number to 2,000 by the year 2020. Vienna has initiated a comprehensive integration of energy and spatial planning into a unified process at the residential district level. This initiative involves the development of energy concepts for existing city districts and new developments. This approach constitutes the foundation for sustainable urban

development, encompassing resource conservation, innovation, and the quality of life of residents (MIRRI SR, 2022c).

### 7.4.2 Examples of successfully implemented energy Smart City project solutions in the EU

**Digitizing District Heating in Aarhus**

In 2017, AffaldVarme Aarhus (AVA), now known as Kredsløb, the heat provider for Denmark's second largest city, completed the implementation of a new smart metering solution from Kamstrup. This solution included 56,000 remotely read hourly heat meters. This initiative signified the initial phase in their endeavors to enhance the efficacy of their district heating system. The system is designed to cater to an expanding number of buildings while promoting a zero-carbon and energy-efficient future. The increased amount of data from the routers brought transparency to the distribution network and enabled a new level of diagnostics and improvements. Consequently, Kredsløb realized substantial benefits and cost savings, attributable to the enhanced performance of their metering system. Concurrently, the administration burden associated with the collection and processing of metering data was mitigated, and the financial implications of rectifying missing or erroneous data were substantially mitigated. Kredsløb is currently engaged in efforts to further digitalize the Aarhus district heating system through the implementation of innovative analytics. The primary objectives of this initiative are to enhance customer relationships, optimize operations, and optimize investments in the heating network.

**Energy Saving in Danish Municipality**

In the European Union (EU), the construction sector is responsible for 40% of total greenhouse gas emissions. Denmark has already initiated measures to curtail greenhouse gas emissions in the energy sector.

Consequently, enhancing energy efficiency in buildings is imperative to attain additional reductions. Since 2017 and for the subsequent four years, the Municipality of Middelfart, in close collaboration with Schneider Electric, has been utilizing Building Analytics to oversee 80 municipal facilities. The software tool under consideration is capable of analyzing substantial amounts of data generated by building management systems and generating actionable reports on energy, indoor climate, and maintenance in real time. The report provides concrete suggestions for addressing inappropriate operating conditions. This enables operational personnel to respond promptly and make decisions as per fact-based analyses. It is estimated that annual energy savings of 5 percent will be achieved, in addition to the 21 percent that the city has already conserved through renovations in comparison to 2008 levels. Consequently, the municipality of Middelfart has achieved a minimum of 26% energy consumption reduction in its buildings (State of Green, 2025).

**GrowSmarter Project**

The GrowSmarter project sought to promote the implementation of intelligent urban solutions. It utilized three "Lighthouse" cities—Stockholm, Cologne, and Barcelona—as case studies, showcasing 12 pioneering solutions for Smart Cities. These solutions encompassed a broad spectrum of domains, ranging from advanced information and communication technologies to optimized urban mobility strategies and the direct integration of renewable energy sources into urban supply networks. The integration of district heating and cooling systems with electricity storage systems, such as batteries for renewable energy storage, holds significant potential for enhancing energy efficiency and sustainability. In Barcelona, the implementation of smart street lighting exemplifies the integration of innovative technology into urban infrastructure. This technology utilizes street lamps as a foundation for sensors, WiFi, and mobile networks, thereby

enhancing the management of public spaces. In the domain of waste recovery, the utilization of waste heat recovery has been employed in various contexts, including the recovery of heat from sewage wastewater, data centers, and waste systems. The integration of waste heat from sources such as refrigeration equipment in supermarkets into district heating systems represents a significant aspect of open district heating. This approach enables the effective utilization of heat residuals from operational processes, contributing to the efficiency and sustainability of the heating system. These elements were instrumental in the execution of the project (European Commission, 2020).

**SPARCS Project**

The SPARCS project is an initiative that aims to demonstrate and validate innovative solutions for the implementation of smart, integrated energy systems. These solutions are designed to be technically, socio-economically feasible, and replicable, with the objective of supporting the transition to a citizen-centric, zero-carbon, and resource-efficient economy. This project was carried out in the Finnish city of Espoo. Energy and mobility are identified as pivotal areas for Espoo, as they serve as the foundation for achieving carbon neutrality. As a Lighthouse city, Espoo will prioritize investments in technologies that support the energy transition and will collaborate closely with residents, businesses, education and research organizations. Espoo's status as a leading city in the UN 2030 Agenda has brought its initiatives and the outcomes of the SPARCS project to the forefront of global discourse. SPARCS in Espoo is a component of the "Sustainable Espoo6" development program, which engages all departments of the local government. The objective of this program is to implement measures that will achieve carbon neutrality by the year 2030, including the elimination of fossil fuel district heating. The following actions were carried

out in the project:

- integration of renewable energy sources towards carbon neutral energy
- integration of district heating and cooling and heat demand response
- predictability and optimization of energy performance
- integration of electric vehicle (EV) charging stations into the local electricity grid and its impacts on the energy system
- monitoring and control of peak loads
- electrification of public transport and charging of electric buses
- research on bidirectional charging stations (European Commission, 2024a).

**The MySMARTLife Project**

The cities of Nantes (France), Hamburg (Germany), and Helsinki (Finland), collectively referred to as "lighthouse" cities, are collaborating with their partner cities, Bydgoszcz (Poland), Rijeka (Croatia), and Valencia (Spain), on a joint project with the objective of integrating ICT technologies, e-mobility solutions, and energy systems. The objective of this initiative is to establish a sustainable urban environment and provide assistance to European cities in their efforts to enhance sustainability. The mySMARTLife initiative is predicated on the concepts of smart population and economy. The project's primary instrument is the implementation of sophisticated urban planning, encompassing a comprehensive approach to urban interventions, a meticulous evaluation of their repercussions, the active involvement of residents in decision-making processes, and a structured economic model. Specifically in Helsinki, the project has equipped the first apartment building with 167 apartments with smart thermostats in every room. These thermostats are connected to the City Platform via the Internet of Things (IoT) technology. The pilot testing of the smart heating control system and the

initial heat demand response tests are currently underway in the designated zones for reconstruction within the mySMARTLife project. Kalasatama, a recently constructed residential area in Helsinki comprising 67 buildings and nearly 4,500 apartments, prioritizes the incorporation of smart technologies across all buildings. Each household will be equipped with smart solutions, including smart meters, which will improve energy efficiency and enable efficient consumption management. The mySMARTLife initiative in this locale will prioritize data collection and collaborative planning for a smart energy district, in close collaboration with the Smart Kalasatama initiative. In this area, measures such as the use of renewable energy sources, waste heat in buildings, and flexible energy demand management are being implemented and evaluated. A pivotal subsequent measure entails the decommissioning of the coal-fired power plant by the conclusion of 2024, which will be accompanied by the introduction of advanced and sustainable energy sources. This constitutes a pivotal challenge within the scope of the mySMARTLife initiative. The mySMARTLife initiative entailed the integration of a sophisticated district-level electricity storage system into an existing solar power plant and a network of electric vehicle charging stations. The system is composed of approximately 15,000 lithium-ion battery cells, which facilitate the temporary storage of electricity generated by the solar power plants in Suvilahti (340 kWp) and Kivikko (850 kWp). These plants are operated by the energy company Helen. The storage system offers a nominal output of 1.2 MW and a capacity of 600 kWh. The initiative promotes the formulation and execution of novel business frameworks and energy strategies. The objective of the present study is to assess the efficacy of multi-user applications in the context of backup power provision, reduction of peak loads, time-based energy distribution, and voltage stabilization (European Commission. 2025h).

**Projekt Smarter Together**

The last practical illustration of this phenomenon is the Smart Together Site Vienna project. The European world cities of Vienna, Munich, and Lyon-the successor cities of Santiago de Compostela, Sofia, and Venice-and the observer cities of Kiev and Yokohama have collaborated to enhance the quality of life for their respective populations. The Smarter Together project laid the groundwork for large-scale replication and facilitated knowledge transfer regarding the development of Smart City business models and user-oriented innovations designed to promote positive social dynamics.

The Smarter Together demonstration area in Vienna is situated in the central part of the south-eastern district of Simmering. The 21,000 residents will benefit from solutions in the areas of renovation, energy, mobility, and information and communication technologies. The project underscores the significance of dialogue, a principle that aligns with the Vienna Smart City Strategy, which places paramount importance on the human dimension of a Smart City. As part of the Smarter Together project, Vienna has sought to:

- renovate three residential districts with 1,300 inhabitants and a total floor area of 75,000 m²;
- achieve savings of 6,000 MWh per year in all renovated housing complexes, which corresponds to the energy consumption of approximately 700 apartments;
- ensure a more sustainable and future-oriented energy supply with 9,000 MWh supplied from renewable sources (both heat and electricity), which will lead to significant savings for tenants on energy and heating costs;
- save approximately 550 tons of CO2 per year;
- secure and/or create 900 jobs;

- support an intensive management training process involving eight departments of the City of Vienna, thus ensuring the permanent integration of the project's experiences and results throughout the city.

The ways in which it has sought to achieve this are as follows:

Energy efficiency in buildings

- Modernisation of building envelope
- Residential and school buildings
- Building systems (ventilation, heating and lighting)
- Installation of heat meters to monitor heat consumption

Energy systems integration

- District heating and cooling
- Connecting multiple users to district heating
- Thermal storage
- Local shared heating: integration of solar thermal energy and thermal storage
- Photovoltaic systems
- Thermal collectors
- Waste heat recovery
- Integration of solar thermal energy and waste heat into district heating
- Smart street lighting
- Innovative street lighting with free WLAN hotspots (European Commission, 2020a).

### 7.4.3 Best practical experiences of smart energy city policy in Slovakia – best practices

Slovakia has witnessed the emergence of numerous pioneering initiatives that prioritize the utilization of contemporary technologies and renewable energy sources for the purpose of enhancing the quality of life for its citizens, mitigating environmental impacts, and enhancing energy efficiency. These projects include initiatives aimed at modernizing public lighting, integrating solar systems, implementing smart sensors, and establishing comprehensive Smart City energy platforms. The following are more detailed examples of specific projects that have been successfully implemented.

A notable success story in Slovakia's energy sector is the *VIBRATe project*, which has been met with considerable acclaim. The implementation period occurred from 2012 to 2014. The initiative established a network of charging stations for electric vehicles, facilitating the dissemination of electric cars and electric scooters to the public. During the project's initial phase, a select group of electric vehicle users had the capacity to charge their vehicles on both sides of the border. The installation of both fast and standard charging stations was carried out in a variety of public and semi-public locations, including parking lots situated within shopping malls. The project yielded substantial environmental benefits, including the mitigation of 7.2 tons of CO2 emissions over a two-year period in Bratislava, concurrently establishing a comprehensive network of charging stations. The following individuals were responsible for the implementation of the project: Západoslovenská energetika has entered into a collaborative partnership with Austrian entities VN, Wien Energie, and VERBUND. The Bratislava Energy Center also participated in the project on the Slovak side. The strategic partners in this endeavor included the Austrian Ministry of Economics

(BMWFJ), the municipalities of Bratislava and Vienna, as well as the regional self-government bodies of Bratislava (BSK) and Lower Austria. The Austrian Institute of Technology functioned as a strategic partner, providing scientific support (Hučková, Svoboda, 2017).

Another successful project in *Prešov* is the *Intelligent Public Lighting project*, implemented between April and May of 2017. The objective of the project was twofold: first, to enhance energy efficiency, and second, to facilitate intelligent process management within the urban landscape. The integration of LED technology in lighting fixtures has been demonstrated to result in substantial energy savings, with the intensity of light being adjustable from 0% to 100% via a mobile device. The system encompassed a range of functionalities, including the reception of emergency signals from citizens, the dissemination of real-time city information, and the monitoring of traffic density and the levels of carbon dioxide in the atmosphere at designated locations. In addition to the function of providing illumination, the poles were designed to support other municipal processes, including the monitoring of parking spaces and the measurement of noise. These functions serve to enhance the project's appeal, as the lighting infrastructure can be utilized for a variety of purposes and is fully reconfigurable according to the city's evolving requirements. A critical aspect of the project implementation involves ensuring sufficient power distribution capacities during the reconstruction of the lighting system. This will facilitate the seamless integration of future solutions. This initiative not only enhances energy efficiency but also fosters sustainability and the intelligent management of urban resources, thereby signifying a substantial advancement in the modernization of urban infrastructure (EKPK, 2023).

The city of *Žilina* has successfully completed a large-scale modernization of its public lighting infrastructure. This initiative involved the

replacement of 3,897 traditional discharge lamps with state-of-the-art LED lamps, representing a significant advancement in energy efficiency and lighting quality. These new lamps were adapted to different types of environments. In city districts and parks, a light yellow color was used, which has been shown to have a pleasant and cozy effect on people. On trolleybus lines and main routes, a neutral white shade was chosen for better visibility and safety. The total investment in the project amounted to approximately 3.2 million euros, which was financed from the Environmental Fund. The scope of the project was expanded beyond the mere replacement of the lamps themselves, encompassing the installation of 226 smart devices and the replacement of 51 lighting switchboards. The integration of advanced lighting control systems with existing infrastructure facilitates the precise modulation of illumination intensity, thereby enhancing energy efficiency and promoting conservation. A significant advantage of modernization is the anticipated electricity savings of up to 60% compared to traditional lighting systems (Mesto Žilina, 2024).

The city of *Veľký Šariš* and the company Východoslovenská energetika a.s. (VSE) presented the first comprehensive Smart City project in Slovakia at the international ITAPA congress on December 8, 2020. The initiative was developed through collaborative efforts with various partners, including Skupina Východoslovenská energetika Holding, SAS Slovakia s.r.o., Antik Telecom s.r.o., and Sensoneo j.s.a. A pivotal initial step in the project involved the installation of photovoltaic panels on the roof of the city hall building in Veľký Šariš, which were commissioned on November 10, 2020. These panels enable the city to utilize solar energy for a portion of its electricity needs, thereby optimizing electricity costs and reducing the city's environmental impact. As part of the Smart City project in Veľký Šariš, VSE also ensures the connection of the heating system to measurement and

regulation via a comprehensive IoT platform, the implementation of smart meters to monitor instant consumption, the optimization of consumption points, the electrification of the local castle, the introduction of an optical network in the city and the adjacent part of Kanaš, as well as the installation of photovoltaic panels and monitoring of green energy consumption (Property & Environment, 2020).

The subsequent section will focus on introducing *the concept of Positive Energy Districts (PED)* through the Horizon 2020 Making City project, in which the Spectra EU Centre of Excellence at STU is collaborating. "PEDs are energy-efficient districts that have net zero carbon dioxide (CO2) emissions and strive for an annual local overproduction of renewable energy (RES)." The objective of the project is to provide support for PED planning and methodology with the aim of developing new integrated strategies to address the transformation of the urban energy system towards low-carbon cities, with the PED approach serving as the core of the urban energy transformation path. The initiative is operationalized at the level of cities and urban districts, which are comprised of two categories of territories: two designated beacon cities and six designated follower cities. The city of Trencin (Slovakia) is one of the cities selected to replicate the Positive Energy District (PED) concept. The PED concept was developed by a project consortium, and it is an urban planning initiative focused on sustainability. The municipality of Trencin is currently prioritizing the diversification of its economic activities, with a focus on the tourism, innovation, culture, and industry sectors. The replication of PED encompasses a more extensive area of the city center, encompassing numerous municipal structures, including schools and sports facilities, as well as residential buildings, comprising both individual housing and apartments (Lindholm & Reda, 2021; Gabaldon Moreno et al., 2021). The fundamental concept of PED is the concept of an

urban district that generates more energy from renewable sources than it consumes, thereby creating an energy surplus. This surplus energy can be exported to other parts of the district, leading to a net export of energy. PEDs have been demonstrated to enhance the quality of life in European cities, contribute to the achievement of the COP21 objectives, and fortify European capacities and knowledge, positioning the continent as a global exemplar. Pedestrian energy districts (PEDs) and concepts such as Positive Energy Neighbourhoods (PENs) are now regarded as strategic keys to decarbonizing the built environment in Europe (Alpagut, Akyürek, Mitre, 2019).

Slovak cities are increasingly focusing their Smart City strategies and plans on improving energy efficiency, using renewable energy sources, and introducing modern technologies for monitoring and managing energy flows. The city of Bratislava has announced its commitment to enhancing the energy efficiency of its public buildings. A key component of this strategy involves the modernization of energy infrastructure. As part of the "*Green Bratislava*" initiative, solar panels were installed on municipal administration buildings, thereby providing energy for lighting and air conditioning. Furthermore, the city has implemented smart energy meters that facilitate real-time monitoring of energy consumption, thereby enabling the optimization of energy expenditures. Additionally, the city of Bratislava has made significant investments in the modernization of its public lighting infrastructure. This initiative involved the replacement of traditional discharge lamps with state-of-the-art LED lighting technology. The implementation of these energy-efficient measures has led to a substantial reduction in energy consumption, with a reported energy savings of 40%. In the domain of heating, the city has demonstrated its commitment to the transition to decentralized heating systems, which integrate renewable sources such as biomass and geothermal energy (Hlavné mesto Bratislava, 2025; MIB, 2021).

*Trencin* is actively involved in projects aimed at integrating renewable energy sources. For instance, in 2021, the city of Trencin received a non-refundable financial contribution from the European Union amounting to over 940 thousand euros for the implementation of the Smart City plan. The city has entered into a collaborative partnership with regional entities to facilitate the development of solar and geothermal energy systems. Solar panels have been installed on several public buildings, including schools and cultural centers, with the objective of covering most of their energy consumption. Trencin has also initiated pilot projects for smart lighting, which are connected to the Internet of Things (IoT) systems to monitor energy consumption and automatically adjust lighting intensity according to current conditions. These measures have contributed to a 20% reduction in the city's energy costs. Another illustration of Smart City solutions in the combined domain of energy and transportation is the recent introduction of public transportation buses that operate on compressed natural gas (Mesto Trencin, 2021; Eco-Logic, 2025; Mesto Trencin, 2022).

The city of *Žilina* has emerged as a prominent leader in the domain of smart energy solutions. The city has invested in the development of distribution networks that enable the integration of local renewable energy sources, such as photovoltaic panels and small hydroelectric power plants. Moreover, the city of Žilina is collaborating with the Technical University to develop smart energy management systems, which facilitate the effective monitoring and regulation of energy consumption in municipal buildings. The system incorporates a predictive analytics component that can forecast variations in energy demand and adapt consumption to the available resources. In the domain of transportation, the city of Žilina has initiated the implementation of electric buses, which are powered by solar and wind energy sources. This initiative aims to promote the integration of renewable

energy sources into the city's transportation infrastructure (Mesto Žilina, 2021).

The Smart City concept in the field of energy in Slovakia is undergoing gradual development within the framework of planned implementations and current status. While in most Slovak cities these are mainly pilot projects and partial initiatives, there are cases that can serve as good practice. In Trencin, the *Making City project*, which is funded by the Horizon 2020 program, is being implemented. The primary focus of the project is the creation of energy communities and the transition to renewable sources. The initiative under discussion is designed to support the creation of urban zones that are energy self-sufficient and produce more energy than they consume. According to the Slovak Smart City Cluster, projects of this nature are intended to facilitate the integration of renewable energy sources and smart infrastructure, with the objective of enhancing the efficiency and sustainability of urban energy systems (Slovak Smart City Cluster, 2018). In the city of Košice, a modernization initiative is underway that involves the implementation of LED technology in the public lighting infrastructure. This step has been demonstrated to reduce energy intensity and operating costs for urban areas. The substitution of traditional lighting sources with light-emitting diodes (LEDs) has been demonstrated to result in energy savings of up to 60%. The Kosice.sk portal asserts that the modernization of lighting constitutes a significant stride towards energy efficiency, while the return on investment is comparatively brief with contemporary technologies (Tokarčík, 2024). The implementation of the Smart Grids concept for optimizing electricity distribution is beginning in Žilina. *Smart grids* facilitate the effective management of energy consumption, thereby reducing losses in the distribution system and enhancing the quality of energy supply. This approach involves the incorporation of renewable energy sources, such as

solar panels and wind turbines, into the existing energy network. As articulated in the European Commission report, Smart Grids embody the foundational infrastructure necessary for the effective utilization of renewable energy sources, facilitating a dual-direction data flow between the provider and the consumer (Wood, 2023).

### 7.4.4 Comparison of Slovakia and the EU in the implementation of Smart City energy concept projects

The Slovak Republic and the European Union (EU) adopt divergent approaches to Smart City energy policy. The EU's strategic framework is significantly more advanced, and its objectives are more expansive. The European Union (EU) has committed to achieving climate neutrality by 2050 and reducing greenhouse gas emissions by 55% by 2030 through the European Green Deal and the Fit for 55 package (Smith, 2022). This objective encompasses the promotion of renewable energy sources, the enhancement of energy efficiency, and the digitalization of infrastructure. Slovakia is adapting its policies to these goals, but to a lesser extent and with limited implementation. The EU's strategy to augment the share of renewables to 19.2% by 2030 is indicative of its commitments, yet the execution of these objectives is frequently impeded by a paucity of financial resources and specialized knowledge.

The European Union (EU) has emerged as a global leader in the implementation of contemporary technologies, including smart meters, IoT sensors, smart grids, and large-scale solar and wind energy facilities. Cities such as Amsterdam, Freiburg, and Vienna have effectively integrated these technologies to enhance energy systems and minimize their carbon footprint. Conversely, Slovakia has opted for a different approach, concentrating on smaller projects such as the modernization of public lighting

systems and the installation of solar panels on public buildings. For instance, the city of Žilina has modernized its lighting infrastructure, resulting in substantial energy savings. However, similar initiatives are still in their nascent stages in most cities. Moreover, Slovakia confronts challenges related to its antiquated infrastructure, which frequently impedes the optimal utilization of renewable energy sources. The European Union (EU) has allocated substantial funding for Smart City solutions through several large-scale instruments, including Horizon Europe, the Modernisation Fund, and the Just Transition Fund. These programs facilitate innovation in the energy sector and empower cities to develop sustainable solutions. In the context of Slovakia, the primary sources of funding are European funds, including the Operational Programme Quality of the Environment and the Recovery and Resilience Plan. These funds have facilitated the implementation of projects in major cities such as Bratislava and Trencin. However, smaller cities and municipalities frequently encounter budgetary constraints and cumbersome funding processes, which hinder their ability to execute similar projects. The European Union confronts substantial challenges in implementing Smart City policies, including the necessity of high initial costs, the imperative for harmonization of legislation, and the critical importance of cybersecurity. However, these issues are mitigated by the presence of effective coordination and substantial support at the EU level. The Slovak Republic faces considerable challenges, including a shortage of experts, outdated infrastructure, and intricate administrative procedures. Furthermore, the absence of a cohesive national strategy for Smart City solutions hinders the coordination between cities and regions. While the European Union has made strides in implementing smart energy solutions, Slovakia is still in the early stages of this development. In order to facilitate more substantial progress in Slovakia, it is imperative to enhance political support, optimize project

coordination, and engage the public more profoundly in the processes of planning and implementing sustainable development. This approach would enable Slovakia to leverage its available resources and technologies more efficiently, thereby aligning its Smart City policy with European standards.

A comparative analysis of Slovak Smart City projects and initiatives within the European Union reveals that European cities offer a number of proven solutions and strategies that can serve as a source of inspiration. Foreign projects frequently integrate technological innovation with long-term strategic planning and robust support from local communities and the private sector. The Netherlands is a prominent example of the successful implementation of Smart City technologies in everyday life. The Amsterdam Smart City initiative places significant emphasis on the integration of renewable energy sources and the active involvement of citizens. Citizens have access to applications and platforms that allow them to directly influence energy consumption and manage energy resources. These systems have been demonstrated to improve energy efficiency and reduce the carbon footprint, while also supporting decentralized forms of energy production, such as community solar panels and microwind turbines. In Denmark, the implementation of Smart City policies is predicated on the comprehensive CPH 2025 Climate Plan, which aims to achieve carbon neutrality (Copenhagen Citizen Service, 2025). Smart district heating networks, which utilize a combination of renewable energy and energy-efficient technologies, are pivotal components of this strategy. Copenhagen is also renowned for its advanced lighting systems, which have the capacity to modulate the intensity of light according to the movement of pedestrians and vehicles. This model has been demonstrated to reduce energy expenditures while concomitantly enhancing the quality of life for residents. In Austria, Smart City policy involves the integration of technology into the domains of transport, energy,

and urban planning. Vienna's strategic emphasis on electric public transportation, encompassing buses and trams, underscores the city's commitment to sustainability. Notably, these electric vehicles are powered by energy derived from renewable sources, further reinforcing Vienna's dedication to environmental stewardship. Another significant project entails the development of a digital platform that empowers residents to monitor their energy consumption and optimize it through the use of smart devices. In Finland, the Kalasatama district represents a pioneering project in this regard. This area functions as a living laboratory where cutting-edge technologies focused on energy efficiency are tested (Forum Virium Helsinki, 2020). The residents have access to advanced energy systems that enable them to monitor consumption and make active decisions regarding its management. Kalasatama serves as a case study, illustrating the integration of innovative technologies into everyday life, thereby optimizing their benefits. A similar degree of success has been achieved in Barcelona, where the Smart City initiative has been implemented with the objective of leveraging sensors and the Internet of Things (IoT) to enhance operational efficiency. The city's infrastructure is equipped with intelligent systems that control lighting, transportation, and waste management. These technologies enable urban areas to utilize their resources in a more efficient manner, thereby reducing detrimental environmental impacts (Vienna Municipal Administration, 2022). A review of international case studies reveals that the successful implementation of Smart City policies is contingent upon long-term strategic planning, the availability of financial resources, intensive interdepartmental collaboration, and public involvement. It is evident that Slovakia possesses the capacity to draw upon these experiences and adapt them to local conditions.

## 7.5 Benefits and limits vs. development potential and opportunities for improving the Smart City energy policy concept

The implementation of Smart City energy policies has been demonstrated to engender a number of benefits that contribute to sustainable development, efficient use of resources, and improvement of the quality of life of the population. However, the implementation of these solutions is not without challenges and limits that can impede or complicate their execution. The objective of Smart City in energy is to establish a sustainable, efficient, and reliable energy system in urban areas by leveraging digital technologies, renewable resources, and active citizen participation. This initiative aims to achieve energy savings, emission reduction, and a comprehensive enhancement of the urban environment. The implementation of Smart City energy policies has been demonstrated to engender a number of significant benefits that exert a long-term positive impact on the energy efficiency, sustainability, and economic viability of urban areas. The benefits are the result of the use of modern technologies and innovations that allow cities to effectively manage their energy resources, reduce operating costs, and minimize their ecological footprint. The primary advantages associated with smart energy can be categorized as follows:

- **Energy efficiency**: optimizing energy consumption in urban systems such as public lighting, heating and cooling, thereby reducing energy intensity and consumption.
- **Sustainability**: using renewable energy sources such as solar and wind sources, and decentralized energy systems that minimize greenhouse gas emissions and contribute to sustainable urban development.

- **Improving the quality of life**: smart energy improves the quality of life of urban residents by reducing negative environmental impacts and improving living and working conditions.
- **Flexibility and adaptability**: flexible and adaptable management of energy systems, which allows for immediate response to changes in energy demand and optimization of its production and distribution.
- **Economic benefits**: saving energy and reducing energy costs, which leads to an improvement in the economic situation of cities, municipalities, regions and their inhabitants.
- **Safety improvement**: improving the safety of cities by monitoring and managing energy systems in real time, leading to a reduction in the risk of injuries and accidents.
- **Communication improvement**: improving communication between citizens, businesses, authorities, leading to improved cooperation and decision-making in the energy sector.
- **Infrastructure improvement**: modernizing and optimizing urban infrastructures such as distribution networks, water supply and sewage systems, thus improving the overall quality of life in cities.
- **Environmental improvement**: reducing greenhouse gas emissions and improving the environment, thus improving the overall quality of life in cities.
- **Technology improvement**: developing new technologies and innovations in the energy sector, thus improving the overall efficiency and sustainability of urban systems.

A primary benefit of Smart City energy policies is the *enhancement of energy efficiency*. Municipalities that adopt smart technologies possess the capacity to monitor energy consumption in real time and analyze data collected through sensors and smart meters. This monitoring method enables

the tracking of consumption, in addition to the prediction and optimization of energy flows within urban systems. To illustrate, smart grids facilitate the effective administration of energy distribution by considering current consumption and the provision of energy from diverse sources. This, in turn, results in enhanced utilization of available energy and a reduction in energy losses. In the city of Barcelona, the implementation of smart meters has been demonstrated to be a highly effective strategy for optimizing energy consumption in urban buildings. This initiative culminated in a 25% reduction in energy consumption, yielding substantial savings in both energy expenditures and CO2 emissions (Minnovation Technologies, 2024a). In Slovakia, the capital city of Bratislava has embarked on a comparable initiative by modernizing energy systems in educational institutions and administrative buildings. This initiative has yielded a reduction in energy expenditures and an enhancement in overall energy efficiency. This optimization is significant not only in terms of economic savings, but also in terms of environmental benefits. A reduction in energy consumption directly contributes to a decrease in the carbon footprint of cities, thereby supporting the achievement of national and international climate goals.

Another pivotal element of Smart City energy policy is *the promotion and incorporation of renewable energy sources*, including solar panels, wind turbines, geothermal sources, and other sustainable technologies.Municipalities that elect to diversify their energy sources experience a reduction in their reliance on fossil fuels and can utilize clean energy solutions that are not only ecologically sustainable but also economically advantageous in the long term.In Žilina, the initiative to install solar panels on public buildings has established a precedent for other Slovak cities. This initiative has led to a substantial enhancement in the city's energy self-sufficiency, primarily due to the adoption of renewable energy sources

to satisfy the energy demands of public buildings. Renewable sources have been identified as a pivotal element in the effort to reduce CO2 emissions in urban areas, thereby aligning with the objectives outlined in the European Green Deal. In Amsterdam, the municipal government has implemented smart systems for integrating renewable energy sources into the city's energy grids. This initiative has resulted in a 15% reduction in CO2 emissions over a period of five years (I amsterdam, 2024). This success was made possible by the effective management and combination of various renewable sources, such as solar and wind energy, with traditional energy systems. Cities in Slovakia, such as Košice and Bratislava, are implementing similar projects and attempting to increase the share of renewable energy sources in their energy mix.

A notable benefit of Smart City policy in the domain of energy is *the financial savings* engendered by the modernization of energy systems. The implementation of smart energy networks and intelligent lighting systems in urban areas has been demonstrated to result in substantial reductions in the operational costs of public services, while concurrently achieving optimal energy efficiency. In the city of Košice, the modernization of public lighting to LED technology has proven to be a highly effective initiative. This initiative has yielded annual savings amounting to hundreds of thousands of euros, with a portion of these funds being reinvested in additional development projects, including the modernization of energy networks and the promotion of electric mobility. This example illustrates how Smart City policy can engender synergy between economic and environmental objectives. The modernization of lighting to smart LED lighting with automatic control according to current conditions (e.g., weather or lighting density) has been shown to result in reduced electricity consumption. These measures have the dual benefits of reducing expenditures and aiding in the

mitigation of CO2 emissions, thereby further promoting urban sustainability (Tokarčík, 2024).

One of the primary objectives of the Smart City policy is *to enhance the energy self-sufficiency of urban areas*. This approach involves the decentralization of energy production, which means that cities and their residents can consume, produce, and share energy. This community energy model is particularly advantageous because it allows municipalities and cities to create local energy systems that are more resilient to fluctuations in energy prices on global markets. This model has been successfully implemented in several European cities and is currently undergoing pilot testing in Slovakia. Trencin serves as a case study, illustrating a municipality that is exploring the notion of community energy (Eco-Logic, 2025). Municipalities that have initiated the implementation of smart energy systems and community solar systems have already experienced a reduction in energy expenditures, a diminution in reliance on external suppliers, and an enhancement in energy autonomy. This approach also supports the active involvement of citizens in solving energy challenges, thereby increasing social engagement and contributing to the enhancement of quality of life.

As part of the overarching Smart City energy policy, there is a commitment to *promoting sustainable mobility*. Urban centers have increasingly prioritized the advancement of electric transportation, shared mobility solutions, and cycling infrastructure. These initiatives are designed to reduce reliance on fossil fuels and to promote environmentally sustainable transportation options. These solutions contribute to reducing emissions and improving air quality. The development of infrastructure for electric vehicles and charging stations in cities such as Bratislava and Košice has been demonstrated to contribute to a reduction in CO2 emissions. Additionally, this initiative has been shown to enhance the availability of green

transportation for residents. The adoption of electric buses and shared mobility solutions by urban centers has been demonstrated to contribute to a reduction in the number of private vehicles on the road. This, in turn, has been shown to result in a decline in air pollution and a reduction in noise levels in urban areas. Furthermore, intelligent traffic management systems that optimize traffic flows and smart parking systems have been shown to contribute to a reduction in traffic congestion, leading to fuel savings and a decrease in emissions associated with inefficient transport (SITA, 2023).

The *economic advantages and benefits* of digitalization and automation of energy systems are evident in the reduction of maintenance and operational costs. For instance, in urban areas that have adopted intelligent energy consumption management systems, the necessity for manual interventions has been diminished, thereby reducing failures. These measures have been demonstrated to result in long-term savings for municipalities and companies.

A primary benefit of implementing Smart City energy solutions is the reduction of energy expenditures and the enhancement of energy efficiency. Intelligent technologies, including smart grids, LED lighting, and renewable energy sources, empower cities and households to substantially curtail energy consumption, thereby reducing financial expenditures. In addition to the financial savings, a significant benefit is the encouragement of business innovation. The implementation of Smart City solutions has been demonstrated to generate employment opportunities in the energy, IT, and construction sectors. The development of smart technologies by Slovak companies, including energy consumption monitoring systems, presents a significant opportunity for the export of their expertise to foreign markets. This development has the potential to enhance the competitiveness of Slovak industry on the global stage.

Smart Cities have been shown to have a *positive impact on the*

*environment*. One of the primary ways in which they contribute to environmental protection is through their use of energy solutions. These solutions have been demonstrated to reduce greenhouse gas emissions and increase the share of renewable energy sources. The foundation of these benefits is the efficient utilization of resources and the optimization of energy infrastructure.

The implementation of solar panels and other renewable technologies on public and private buildings is a highly effective measure towards sustainable energy. In the city of Bratislava, a number of solar power plants were installed on the roofs of schools and municipal institutions as part of the Green City project. These panels ensure the supply of clean energy for the operation of buildings and will reduce CO2 emissions by 120 tons per year (Euroactive, 2024). As asserted by Climate-KIC, strategic investments in renewable energy sources are imperative for the successful attainment of climate objectives and the enhancement of air quality. Another pertinent example is the modernization of transportation through electromobility. In the city of Košice, several electric buses have been introduced, along with charging stations for public use.

This initiative has resulted in a 30% reduction in greenhouse gas emissions and local air pollution in the city's central areas (Techbox, 2024). Intelligent traffic management systems that optimize traffic flow and minimize time spent in traffic jams are equally crucial in achieving this objective, as they can further reduce emissions. The environmental benefits of smart buildings are evident in the reduction of energy consumption, achieved through the implementation of intelligent heating and lighting systems. These systems facilitate real-time optimization of energy consumption and the prevention of unnecessary waste.

## 7.6 Main challenges and limits in implementing smart energy in cities

The implementation of smart energy in urban areas poses several challenges that must be addressed to ensure its successful integration into urban planning and management. Addressing these challenges necessitates a comprehensive approach that incorporates technological, regulatory, financial, and social dimensions. The successful implementation of smart energy in urban areas is contingent upon collaboration between cities, technology providers, investors, and citizens.

The primary challenges associated with the implementation of smart energy systems can be enumerated as follows:

Technology Integration

- Connecting different technologies and systems, such as smart grids, renewables, energy storage and smart buildings;
- Ensuring compatibility and interoperability between systems from different vendors.

Cybersecurity

- Protecting large data flows and critical infrastructure from cyber threats;
- Ensuring the privacy and security of data collected from smart meters and sensors.

Financing and Investment

- Ensuring sufficient financing for costly investments in energy infrastructure modernization;
- Finding suitable business models and sources of financing for smart energy solutions.

Regulation and Standards

- Creating an appropriate regulatory framework for the integration of renewables and new technologies;
- Defining standards for interoperability and data exchange between different systems.

Data Infrastructure

- Ensuring sufficient data infrastructure for the collection, transmission and analysis of large amounts of data;
- Creation of platforms for sharing and using data between different entities (PVcase. 2024).

The implementation of the Smart City policy in the energy sector introduces *limitations* that have the potential to impede the effective implementation of these solutions. These challenges and risks are diverse in nature and include security, financial, technological, legislative/administrative, and social aspects that require thorough analysis and strategic solutions.

*Security concerns* represent a significant impediment to the implementation of the Smart City policy. The advent of digital technologies in the energy sector has concomitantly engendered an augmented risk of cyberattacks. The implementation of smart grids and the proliferation of IoT devices have rendered energy infrastructure susceptible to cyber-attacks. Such breaches have the potential to disrupt energy supplies and cause significant damage to urban systems. In the Slovak Republic, the issue of cybersecurity is not yet accorded the priority it deserves, thereby increasing the vulnerability of new technologies. Furthermore, it is imperative to prioritize the safeguarding of personal data, as smart meters and sensors amass a substantial amount of information regarding energy consumption and the behaviors of residents. Inadequate protection of this data can result in public distrust and resistance to the implementation of new solutions.

The presence of *financial constraints* is a notable challenge. A significant impediment to the implementation of Smart City energy policy solutions is the high initial investment costs. The introduction of smart technologies and the modernization of infrastructure require substantial initial investments. The development and deployment of smart technologies in the energy sector necessitates substantial financial resources, which many cities, municipalities, and private entities are unable to cover independently. These costs encompass not only the technology itself, but also research, planning, implementation, and subsequent maintenance of the systems, which represents a complex financial burden. Many cities, particularly smaller ones, face budgetary constraints and a paucity of resources that would enable them to implement ambitious projects. Despite the financial assistance provided by European funds, such as the Recovery and Resilience Plan of the Slovak Republic, the utilization of these funds is frequently encumbered by administrative requirements and intricate procedures. Consequently, a number of projects have been postponed or even completely suspended. The long-term economic benefits, including energy savings, are often only evident after a considerable period, which can diminish the impetus for cities to initiate the implementation of these solutions. In smaller Slovak cities, such as Levoča, the planned modernization of public lighting was suspended precisely due to a lack of financial resources. The mayor of the city has asserted that, despite the anticipated financial savings resulting from the adoption of modern technologies, the initial costs are too substantial for the municipality to implement them without subsidies. A further issue is the lack of motivation for the private sector, which perceives the return on investment in smart solutions to be long-term. A significant proportion of intelligent projects, particularly within the energy sector, exhibit protracted return on investment periods, a circumstance that has the effect of deterring prospective

investors. As stated in a report by the International Renewable Energy Agency (IRENA), cities must implement comprehensive financial models and establish partnerships between the public and private sectors to successfully finance smart projects (IRENA, 2024; SBA, 2024).

The existence of *technological barriers* is a salient factor in this context. The technological readiness of cities constitutes an additional significant limit. The implementation of contemporary technologies, including smart meters, IoT systems, and decentralized energy networks, necessitates a significant degree of expertise. Technological unreadiness is therefore a significant obstacle that hinders the deployment of smart solutions. In the Slovak Republic, a significant portion of the distribution networks remains antiquated, impeding the comprehensive integration of smart systems. The implementation of smart systems, including smart grids, smart public lighting, and energy consumption monitoring systems, hinges upon the existence of a robust infrastructure. Absent this element, the implementation of sophisticated technological solutions becomes impractical or exhibits a constrained scope. The implementation of Smart City energy solutions is largely contingent upon the availability and readiness of the technological infrastructure. Many cities and regions, particularly in Eastern Europe, face challenges due to their antiquated energy systems, which often lack the capacity to integrate with contemporary smart technologies. To illustrate, antiquated distribution networks frequently prove incapable of accommodating decentralized energy sources, such as solar panels or wind turbines. This limitation restricts the full realization of their potential. A case in point is the implementation of Smart Grids in Banská Štiavnica, where the reconstruction of a segment of the distribution system proved to be a prerequisite, resulting in an escalation in project costs and an extension in the implementation timeline (Energium, 2020). Moreover, the issue of

technology fragmentation and the absence of interoperability among distinct systems is a salient concern. The European Commission has noted that the absence of uniform technical standards for smart energy solutions hinders their extensive utilization in practice (European Commission, 2025i). In many cases, cities and companies are compelled to adopt solutions from disparate suppliers, a practice that often gives rise to integration and compatibility challenges.

The presence of *legislative and administrative barriers* has been identified as a significant impediment to progress. Administrative obstacles and legislative restrictions represent a significant challenge. In the Slovak legislative environment, there is often a lack of preparation for the implementation of concepts such as community energy or smart grids. Furthermore, the absence of a cohesive, overarching strategic framework at the national level engenders a paucity of coordination between cities and regions, which can result in the duplication or conflict of individual initiatives (Minnovation Technologies, 2024b). In the energy sector, for instance, antiquated regulations can impede the potential for energy sharing between households or the effective integration of renewable energy sources into public energy networks. Additionally, there is a paucity of explicit guidelines concerning intelligent transport systems or personal data protection in the context of sensor and device utilization within urban environments. A case in point is the regulation of distribution networks and ownership of energy infrastructure in Slovakia. Municipalities and cities possess limited authority in the domain of energy administration, a circumstance that impedes their capacity to execute intelligent solutions within their respective jurisdictions. As indicated in a report by the Regulatory Authority for Network Industries (ÚRSO, 2022), the prevailing regulatory frameworks require fundamental reform to facilitate more flexible utilization of energy innovations. Another

challenge pertains to the protracted approval procedures and the administrative load associated with the execution of projects that are financed from EU funds. A notable example is the solar power plant construction project in the Nitra region, which experienced a delay of more than two years due to the complexity of permits and the evolution of legislative conditions (MIRRI, 2017).

The introduction of new technologies can be impeded by *social and cultural factors*. The limited digital literacy and technological distrust among residents contribute to the underutilization of Smart City solutions. The social acceptance of Smart City energy projects is also a significant challenge. If residents do not comprehend the advantages of smart solutions or harbor concerns regarding their potential disadvantages, such as privacy violations or increased costs, they may actively impede their implementation. A 2022 survey administered by the Public Opinion Research Agency revealed that up to 42% of Slovaks lack sufficient information regarding the Smart City concept and its purported benefits. For instance, in Bratislava, a portion of the population voiced their opposition to the implementation of smart meters, citing concerns regarding the collection of personal data and the monitoring of energy consumption (Vávra, 2022).

The implementation of smart energy policy in Slovakia is hindered by several factors, primarily *the absence of a national strategy*. The nation currently lacks a comprehensive national strategy that would clearly define its goals and priorities in the field of Smart Cities. Despite the existence of individual initiatives and projects, the absence of a unified direction results in cities and municipalities proceeding in an uncoordinated and unsystematic manner. The implementation of a national strategy would facilitate the optimization of available resources, the harmonization of legislation, and the provision of methodological support to cities in the execution of their

projects. The absence of subject matter experts is a salient issue in Slovakia's implementation of Smart City solutions. The necessity for a team of qualified experts to develop and implement these solutions is fundamental, yet this is an area of deficiency in Slovakia. These professionals are experts in the fields of information technology, energy, urban planning, and environmental studies. The implementation and management of these solutions can be hindered by a lack of available experts, which can lead to reduced effectiveness and sustainability.

## 7.7 Opportunities and development potential

The implementation of Smart City policies in the domain of energy presents a multitude of opportunities that have the potential to markedly enhance the quality of life for residents and promote sustainable urban development. A significant opportunity exists in *the development of renewable energy sources*. The potential exists for Slovakia to make more intensive use of resources such as solar and wind energy, or geothermal sources. These resources have the capacity to assist in reducing the country's dependence on fossil fuels while concurrently supporting energy decentralization. Smart energy grids represent a significant opportunity. These networks facilitate the more efficient management of energy distribution, the reduction of losses, and the involvement of consumers as active market participants. In conjunction with energy storage technologies, smart grids have the potential to enhance the stability of energy supplies and facilitate their optimization (Ministry of Economy of SR, 2025).

*Digitization* is a pivotal component of contemporary energy management. The advent of digital solutions, such as smart metering devices and advanced analytical tools, has enabled the real-time monitoring and optimization of energy consumption. These technologies also promote

sustainable consumer behavior by providing consumers with a comprehensive overview of their energy consumption and options for reducing it.

*The establishment of energy communities*, wherein individuals and households engage collectively in the production and consumption of energy, presents a significant opportunity. The establishment of such communities has been demonstrated to have the potential to enhance social cohesion, reduce energy expenditure, and contribute to the development of local economies. In the context of the formulation of Smart City policies, a substantial opportunity for collaboration exists between the public and private sectors. Public-private partnerships have the potential to facilitate not only the financial aspect of project implementation but also the dissemination of specialized knowledge and the integration of technological advancements. This collaborative effort has the potential to expedite the implementation of intelligent solutions and enhance their efficacy. Another salient factor is the support from the European Union, which provides financial resources as well as inspiration from successful projects within the member states. The European Union's (EU) programs and initiatives, including the Green Deal and Horizon Europe, present avenues for acquiring funding and expert counsel in the execution of Smart City projects (European Commission, 2025g).

Another significant opportunity is *cooperation with the private sector*. The collaboration between municipal authorities and private investors has been demonstrated to facilitate more efficient project implementation, not only in terms of financial resources, but also in terms of technical expertise and the integration of innovative technologies. A notable example is the collaboration between the city of Košice and local companies in the modernization of public lighting, which involved the implementation of

energy-saving and intelligent LED technologies. The potential for this model of cooperation extends to other domains, including smart grids, transport electrification, and the utilization of renewable energy sources.

Furthermore, Slovakia stands to benefit from the *strategic initiatives employed in other European cities*, which have demonstrated success in addressing these challenges. As demonstrated by the case study of the city of Amsterdam, the integration of smart technologies into the urban environment has been shown to yield a synergistic effect between sustainable development and economic growth. The implementation of intelligent energy solutions in Amsterdam has resulted in a decline in energy consumption among households and an augmentation in the utilization of renewable energy sources. An additional compelling exemplar is Copenhagen, which implemented an integrated system for monitoring and optimizing energy consumption in urban buildings, thereby achieving a substantial reduction in greenhouse gas emissions. Conversely, Vienna exemplifies a paradigm for integrating energy solutions with intelligent transportation, wherein smart technologies facilitate enhanced coordination of urban mobility and its integration with renewable energy sources. The strategic implementation of Smart City solutions in the field of energy has been demonstrated to yield tangible outcomes, including the reduction of CO2 emissions, energy savings, and the enhancement of the quality of life for residents. The advent of sophisticated tools, the accumulation of foreign experience, and the growth in potential within the domain of digitalization have endowed Slovakia with a distinctive opportunity to assume a leadership role in the Central and Eastern European region in the domain of Smart City solutions. However, to successfully leverage these opportunities, it is imperative to enhance coordination between the state, local governments, and the private sector. Moreover, fostering education and awareness in this domain is paramount.

## 7.8 Summary

In conclusion, Smart City energy policy is a foundational instrument for cities aspiring to achieve sustainable development, enhance the quality of life of their residents, and concurrently address climate challenges. While the European Union has made significant progress in this area, Slovakia is in the early stages of implementation. The development of smart technologies, the use of renewable energy sources, and increased citizen participation are key success factors that require active political, financial, and technological support. The integration of smart technologies has been demonstrated to facilitate enhanced resource efficiency, curtailed energy intensity, and the promotion of sustainable development. A significant component of these strategies involves the utilization of renewable energy sources and technologies to mitigate greenhouse gas emissions. However, the successful implementation of smart solutions necessitates effective cooperation between the public sector, private entities, and citizens. The European Union is establishing a framework for the development of sustainable cities through legislative instruments and initiatives, such as the SET Plan. Projects such as GrowSmarter, SPARCS, mySMARTLife, and Smarter Together exemplify the successful implementation of innovative technologies, renewable energy sources, and smart mobility solutions in real-world settings. Each project also offers valuable insights and inspiration in solving energy problems in other cities, which contributes to the sharing of best practices at European and global levels. The results obtained, including the reduction of CO2 emissions, energy savings, and the development of e-mobility, substantiate the efficacy of these measures. These projects serve as a testament to the notion that Smart Cities are not merely a future technological advancement, but rather a strategic approach that enables cities to address the challenges posed by climate change, urbanization, and technological progress. By integrating

innovation, sustainability, and citizen participation, they establish a paradigm that serves as a source of inspiration for the advancement of urban development. The implementation of Smart City solutions in the domain of energy has been demonstrated to engender numerous advantages, including the mitigation of greenhouse gas emissions, the enhancement of energy efficiency, and the augmentation of the quality of life for residents. These factors are critical for adapting cities to climate change and reducing environmental burdens. A notable added value is the potential for fostering economic growth through investments in smart technologies, which have been shown to generate new employment opportunities and fortify regional economies. However, the implementation of these solutions faces challenges such as financial complexity, technological unpreparedness, and administrative barriers that slow down the introduction of innovative projects. The Slovak Republic faces several challenges in this regard, including a shortage of experts, outdated infrastructure, and a lack of public awareness regarding the benefits of these solutions. Furthermore, it is imperative to address the issues of cybersecurity and personal data protection. Slovakia stands to benefit from the strategic initiatives successfully implemented in cities such as Amsterdam, Freiburg, and Vienna. These cities demonstrate that a collaborative effort involving technological innovation, effective governance, and citizen involvement can transform urban areas into energy self-sufficient and ecological units. Notwithstanding the prevailing challenges, it is imperative for Slovakia to dedicate efforts to addressing its deficiencies and adopting the best practices established by the European Union. This transformation has the potential to make a substantial contribution to the achievement of climate objectives, enhance the quality of life for residents, and fortify the nation's economy. It is imperative for Slovakia to enhance coordination between the national and regional levels,

optimize the utilization of available financial resources, and augment citizens' awareness of the advantages of Smart City solutions. The resolution of prevailing challenges, including but not limited to antiquated infrastructure, dearth of specialists, and legislative impediments, will enable Slovakia to incrementally enhance its competitiveness and the quality of life for its inhabitants. Concurrently, the nation will become an integral component of a comprehensive endeavor within the European Union to construct sustainable and intelligent urban centers. This approach will not only contribute to meeting climate goals but also strengthen Slovakia's position within the European space.

The Smart City concept is a modern and innovative approach to urban development that utilizes technology to enhance the quality of life for residents, increase resource efficiency, and support sustainable development. As demonstrated in this chapter's analysis, energy, as one of the primary components of a Smart City, plays a pivotal role in the transformation of cities into intelligent and ecological environments. Despite its limitations in implementing Smart City solutions, Slovakia is demonstrating positive progress in the development of intelligent energy systems. Significant examples of the implementation of Smart City solutions in Slovakia have been identified. Projects such as energy communities in Trencin, the modernization of public lighting in Košice, and the introduction of smart grids in Žilina exemplify the potential of innovations aimed at enhancing energy efficiency and sustainability. These initiatives yield two major benefits: economic savings and environmental benefits. The former includes reduced CO2 emissions, while the latter includes support for renewable energy sources. Concurrently, a series of barriers impeding the development of Smart City solutions in Slovakia have been analyzed. The most pressing challenges that must be addressed include financial constraints, legislative

ambiguities, inadequate technical infrastructure, and limited citizen participation. The initial financial commitments required for the implementation of contemporary technologies, including smart meters and distribution networks, are often substantial. This is particularly salient in smaller cities with constrained financial resources. The dearth of a stable legislative framework and the inadequate technical readiness of urban energy networks impede the effective implementation of innovations. Furthermore, the dearth of awareness among residents regarding the merits of Smart City solutions has been identified as a key factor in the weakening of support for these initiatives. Despite these challenges, Slovakia possesses considerable potential for the advancement of smart solutions in the energy sector. The utilization of available European Union funds, including Horizon Europe and the European Green Deal, has the potential to assist in overcoming financial obstacles and providing support for innovative projects. Furthermore, the collaboration between municipalities and private enterprises has been demonstrated to facilitate the more efficient implementation of technological solutions. Slovakia stands to benefit from emulating the success of other nations in integrating Smart City technologies, a strategy that has been demonstrated to foster a symbiotic relationship between economic growth and sustainable development. In the context of Smart City, energy is not merely a matter of technological implementation; rather, it is a comprehensive strategy for enhancing urban life. The implementation of contemporary solutions, including smart grids, renewable energy sources, and intelligent energy management, offers urban centers the potential to curtail energy expenditures, enhance the quality of life for their inhabitants, and concurrently promote environmental sustainability. However, to achieve these objectives, it is imperative to enhance legislative support, educate the public, and increase civic engagement. It is imperative to underscore that the

implementation of Smart City solutions in the domain of energy is not exclusively the purview of large cities. It is evident that smaller Slovak cities have the potential to benefit from innovations, provided that they receive the necessary support. The Smart City concept is not merely a goal, but rather a process that necessitates a comprehensive, long-term strategy, effective cooperation at all levels of government, and a resolute determination to overcome the existing barriers. In this manner, Slovakia can meaningfully contribute to the achievement of the climate objectives of the European Union and ensure a sustainable future for its cities and their inhabitants.

# CHAPTER 8. EVALUATION OF THE QUESTIONNAIRE SURVEY – SMART SOLUTIONS FOR MUNICIPALITIES WITHIN THE SLOVAK REPUBLIC

As part of the project, a questionnaire survey was conducted with the aim of identifying key areas and factors determining the procedures and attitudes of local government in the Slovak Republic. The questionnaire was conducted between January and September 2025. A total of 100 municipalities were surveyed, with a response rate of 60%. The questionnaire contained 17 questions, of which 8 were closed questions and 9 were open questions. All 60 returned questionnaires were correctly completed and none were excluded during the selection process. The questionnaire focused mainly on areas that are in line with the goals of the 2030 Agenda for Sustainable Development.

## 8.1 Evaluation of the questionnaire survey

The aim of question 1 was to identify what priority they consider to be the implementation of SMART elements for individual areas (see Figure 8.28).

High Priority dominates across all areas, with counts ranging from 20 to 34, indicating that most respondents consider SMART elements highly important. Maximum Priority also shows significant values (10–18), suggesting strong support for top-level prioritization, especially in City Development Strategy/Program and Citizen / Quality of Life.

Regional Development Strategy (22) and EU Strategies (18) show moderate emphasis. City Development Strategy/Program (8) and Citizen / Quality of Life (6) are much lower, suggesting these areas are either seen as very important or not important at all. Low Priority and No Priority are negligible (mostly 0–2), confirming that respondents rarely dismiss SMART elements entirely.

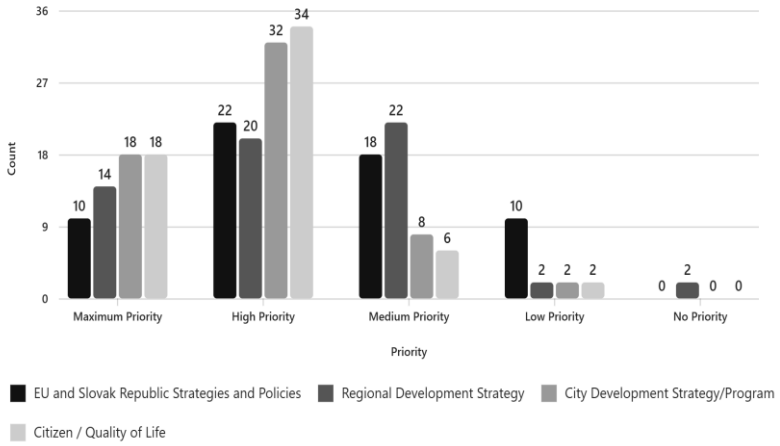



Figure 8.28

To what extent do you consider the introduction of SMART elements to be important in relation to the given areas?

Source: own research

Citizen / Quality of Life has the highest High Priority count (34), signaling that respondents strongly associate SMART initiatives with improving quality of life. City Development Strategy/Program leads in Maximum Priority (18), showing strong preference for urban-focused SMART solutions. Regional Development Strategy stands out for Medium

Priority (22), suggesting a balanced view - important but not critical. EU and Slovak Republic Strategies and Policies show a relatively even distribution between Maximum, High, and Medium Priority, indicating a more consistent perception of importance.

SMART elements are perceived as highly important across all strategic areas. Urban and citizen-focused initiatives receive the strongest emphasis. Regional and EU strategies are important but show more moderate prioritization. Negligible support for Low or No Priority categories confirms overall consensus on the relevance of SMART solutions.

In the second question, cities could select multiple answers regarding activities that the city implements within the framework of SMART issues (see Figure 8.29).

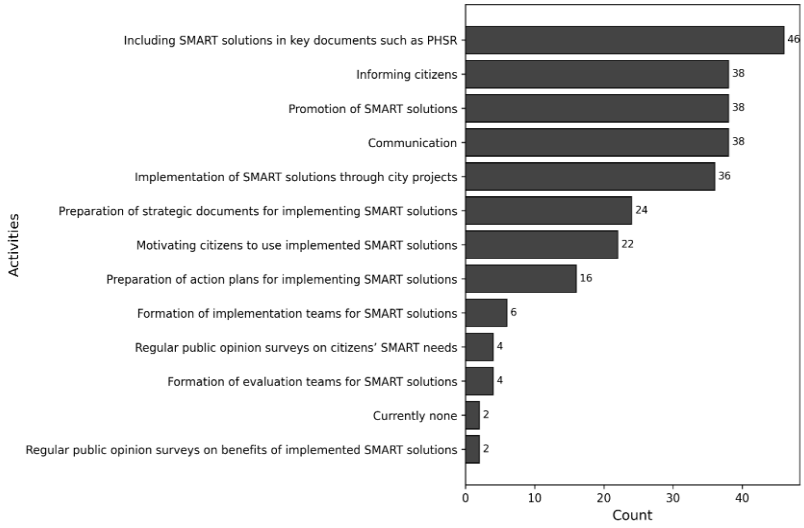



Figure 8.29

Which activities does the city implement within the framework of SMART issues?

Source: own research

Inclusion of SMART issues in key documents such as Program of Economic and Social Development (PHSR) and Preparation of strategic documents for SMART implementation appear among the most frequently mentioned activities (see Figure 30). This suggests that cities prioritize strategic planning and integration of SMART concepts into official frameworks. Informing citizens, communication, promotion of SMART solutions also ranks high, indicating strong emphasis on public awareness and engagement. Implementation of SMART solutions through city projects is another major activity, reflecting practical application beyond planning.

Motivating citizens to use implemented SMART solutions and Preparation of action plans for SMART implementation show moderate frequency. These activities are important for adoption but seem less prioritized compared to strategic and communication efforts. Activities related to formation of implementation teams and evaluation teams occur less often, suggesting that organizational structures for SMART initiatives are still developing.

Regular public opinion surveys (both on SMART needs and benefits) and None at the moment have the lowest counts. This indicates limited systematic feedback collection and that some cities have not yet started SMART-related activities. Strategic integration and communication are the most common SMART activities. Practical implementation through projects is significant but secondary to planning. Activities related to monitoring and evaluation are minimal, indicating a gap in feedback and performance assessment. Some cities report no SMART activity, highlighting disparities in adoption.

The following figure shows the responses to an open-ended question aimed at determining the status of the implementation of the SMART concept in documents. Program of Economic and Social Development (PHSR) has the highest frequency, significantly exceeding all other documents.

This indicates that most cities integrate SMART concepts primarily into their general development strategy rather than creating separate SMART-specific plans. Integrated Urban Strategy, Low-carbon Strategy, and Safe City appear with moderate counts. These documents suggest a focus on sustainability and safety alongside SMART initiatives. Other answers were: Urban Innovation Concept and Bratislava 2030, Public Lighting Audit, Development Concept for EV Charging Infrastructure, and Climate Adaptation Action Plans.

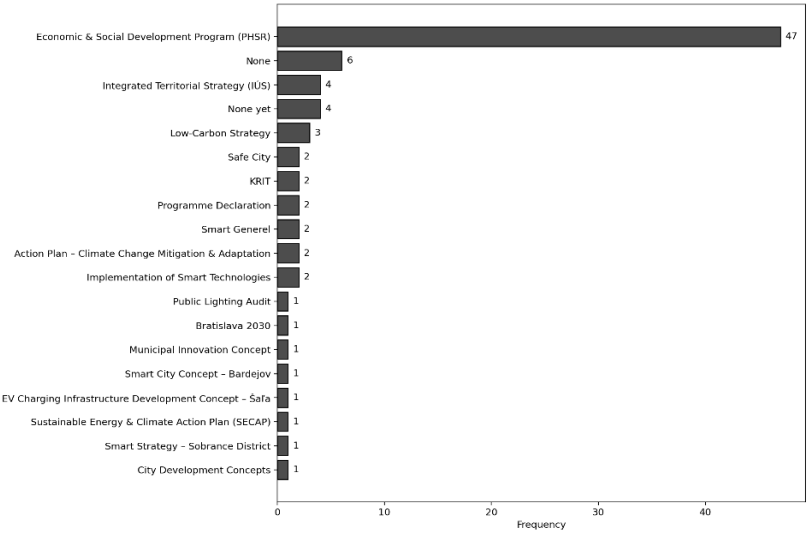



Figure 8.30

In which program documents has the city incorporated/is incorporating the SMART concept?

Source: own research

Categories like None and, None yet, indicate that some cities have not yet incorporated SMART concepts into any strategic documents. Sustainability-related documents (Low-carbon Strategy, Integrated Urban Strategy) are

secondary but important. A significant number cities has not yet started formal SMART integration.

In question 4 (see Figure 8.31), we asked what activities the city has implemented/is implementing as part of the SMART concept.

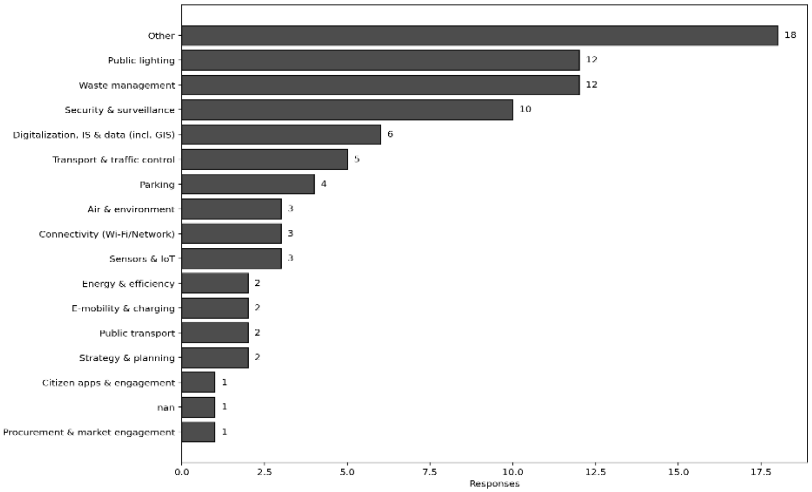



Figure 8.31

What activities has the city implemented/is implementing as part of the SMART concept?

Source: own research

Public lighting and Waste management are the two most frequently reported SMART activity areas, each with 12 responses (both 20% of all respondents). This indicates a strong, infrastructure-first orientation focused on visible savings and operational efficiency. Security & surveillance follows closely with 10 responses (16.7% of all respondents), underscoring demand for camera systems and video analytics that produce a tangible sense of safety. The largest number of responses, "Other," includes responses that

could not be directly assigned to a specific area when aggregating responses. These responses were attributed to a specific area, e.g., project preparation, meetings with partners, document processing, analysis creation, etc.

Digitalization, IS & data (incl. GIS): 6 responses (6.9%), suggesting ongoing but less dominant efforts to modernize internal systems and data platforms. Transport & traffic control: 5 responses (8.3% of all respondents), slightly ahead of Parking (4 responses, 6.7% of all respondents), implying cities prioritize traffic flow and safety before parking reforms. Air & environment, Connectivity (Wi-Fi/Network), and Sensors & IoT each have 3 responses (5% of all respondents). Emerging areas like Energy & efficiency, E-mobility & charging, Public transport, and Strategy & planning appear only twice (3.3% each). Rare mentions (1.6% each): Citizen apps & engagement, Procurement & market engagement, and None.

The next question focused on what activities the city plans to implement through the SMART concept. Hard infrastructure themes dominate plans (waste, energy, parking, buildings). Waste Management (15% of all respondents) plans focus on expanding weighing systems, improving sorting, and optimizing collection. This reflects cost-reduction goals and compliance with environmental regulations. Energy & Efficiency (11.7% of all respondents) cities plan energy-saving measures, metering, and building management (often via IoT): “energy efficiency in public buildings”, “Energy management of municipal buildings via IoT”.

Parking & Parking Policy (11.7% of all respondents) change from “comprehensive parking solutions” to “city parking system”. Buildings & Infrastructure (10% of all respondents) mainly focuse on: “building renovation”, “infrastructure”, “wastewater treatment plant”; emphasis on capital projects improving service quality and often linked to energy savings. Digitalization, IS & Data (11.7% of all respondents). These projects prepare

for process automation, unified citizen identity, and interoperable data governance.

Transport control/monitoring (8.3% of all respondents) is practical step with immediate impact on flow and safety. Public Lighting (5% of all respondents). E-Mobility & Charging (1.67% of all respondents) – “building a network of EV charging stations” (selective adoption). Metropolitan Network & Connectivity (1.67% of all respondents) – infrastructure prerequisite for IoT/data. Strategy & Project Management (8.3% of all respondents) Planning and preparation of documents/projects indicate efforts to align direction and build a project pipeline.

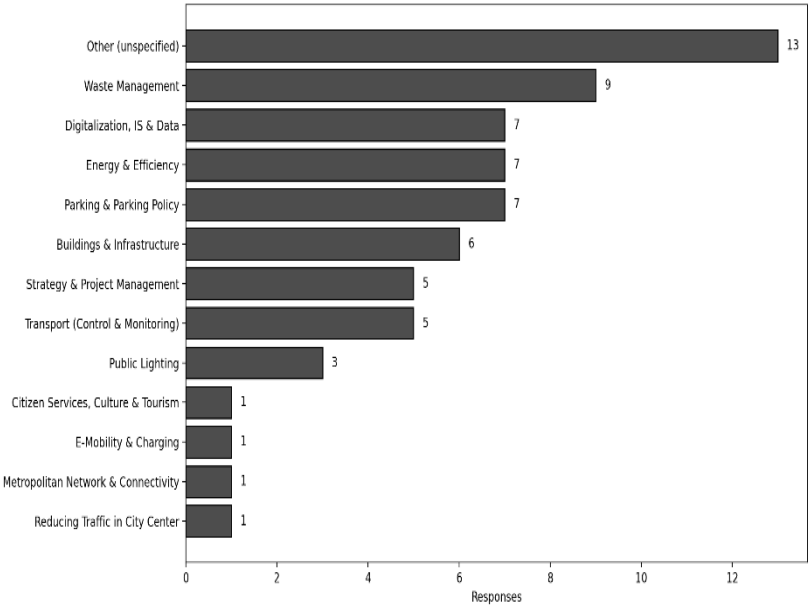



Figure 8.32

What activities will the city implement through the SMART concept?

Source: own research

The municipalities responded as follows to the question of the status of implementation of the SMART concept (see Figure 8.32). Across the dataset, municipalities most frequently report being in a “Partial implementation” stage, with 22 responses (36.7%), closely followed by the “Initial phase” at 20 responses (33.3%). Together, these two categories account for 70% of all responses, indicating that the majority of cities are either actively rolling out selected SMART components or are in the early steps of piloting and preparation. This pattern suggests broad adoption in progress rather than a mature steady state.

A smaller yet notable segment, “None” with 10 responses (16.7%), signals that a subset of municipalities either has not started or does not currently identify their activities under a SMART label. Reasons may include limited capacity, funding constraints, or a focus on foundational preconditions (strategy, procurement, or infrastructure) before declaring formal SMART initiatives.

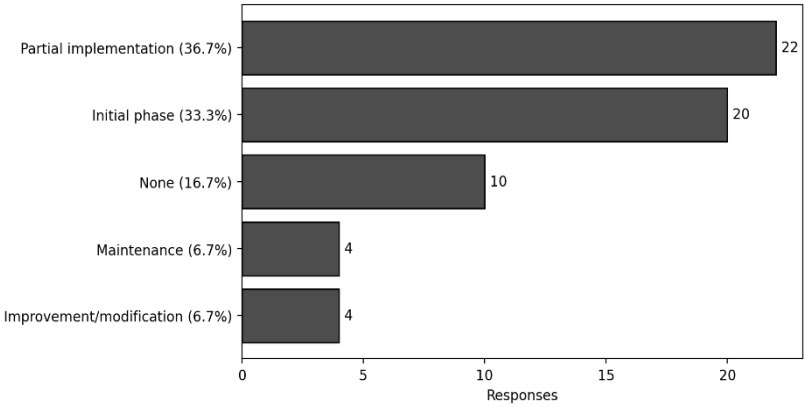



Figure 8.33

What is the status of the SMART concept implementation?

Source: own research

The truly advanced ends of the lifecycle “Improvement/modification” and “Maintenance” are each marked 4 times (6.7% per category). These responses indicate pockets of maturity where solutions are already deployed and are either being optimized (fine-tuning, adding AI/analytics, expanding scope) or routinely maintained and integrated into city operations (see Figure 8.33).

However, their relatively low frequency compared to “Partial”/“Initial” underlines that, system-wide, most cities are not yet in a stable run-state; rather, they are navigating the build-out and transition from pilots to broader implementation.

Our findings regarding the question of what financial resources the city uses to fund the SMART concept were as follows (see Figure 8.34).

So summing across all activities (540 total selections), two signals dominate and are almost neck-and-neck: “Own only” accounts for 38.5% of responses while “None” accounts for 37.8%. The remaining share is led by “Own+EU” (8.1%), followed by “Own+EU+Grants” (3.7%), “Own+Grants” (2.6%), and “EU only” (4.1%). Single-source reliance on grants (1.1%) or the state budget (0.7%) is rare. In practical terms, cities tend to either finance activities purely from their own budgets or not fund them at all, with EU and grant money most often appearing in combination with own resources rather than alone.

For preparing strategic documents, cities most often rely on own only funding—46.7% (28/60)—while 20.0% (12/60) report None, and 16.7% (10/60) use own+EU; this indicates that strategy work is primarily covered from municipal budgets with a secondary role for EU co-financing. By contrast, Informing & communicating with citizens is strongly supported from municipal budgets: 70.0% (42/60) own only, with just 10.0% (6/60) none and 6.7% (4/60) own+EU, reflecting a communications-first posture.

For ,otivating citizens to use SMART, 50.0% (30/60) own only and 33.3% (20/60) none dominate, with 6.7% (4/60) own+EU; motivation programs exist but still face notable underfunding. Regular surveys: citizens' SMART needs are largely unfunded 60.0% (36/60) none while 33.3% (20/60) are own only and 3.3% (2/60) Other only; evidence-building and voice-of-citizen mechanisms are systematically neglected. Finally, regular surveys: evaluating benefits of deployed SMART show 56.7% (34/60) none, 36.7% (22/60) own only, and 3.3% (2/60) own+EU, confirming that post-implementation evaluation is rarely budgeted for and, when it is, it mainly relies on municipal funds.

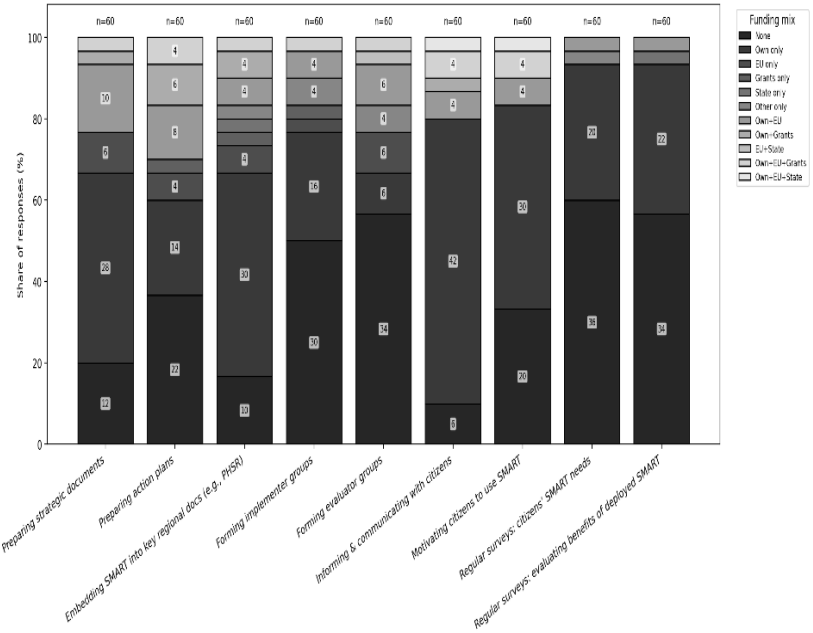



Figure 8.34

What financial resources does the city use to fund the SMART concept?

Surce: own research

The evaluation of the question regarding the weight of individual motivators related to the SMART concept is presented in the following figure (see Figure 8.35).

Overall, the distribution is strongly skewed to higher priorities: across all 11 motivators (660 total responses), “5 – highest priority” accounts for ~34% of selections, while “4 – higher priority” adds ~41%; by contrast, “3 – medium” is ~18%, “2 – lower” ~6%, and “1 – lowest” ~1%. In other words, respondents overwhelmingly frame these motivators as important to very important, with only marginal support for the lowest tiers.

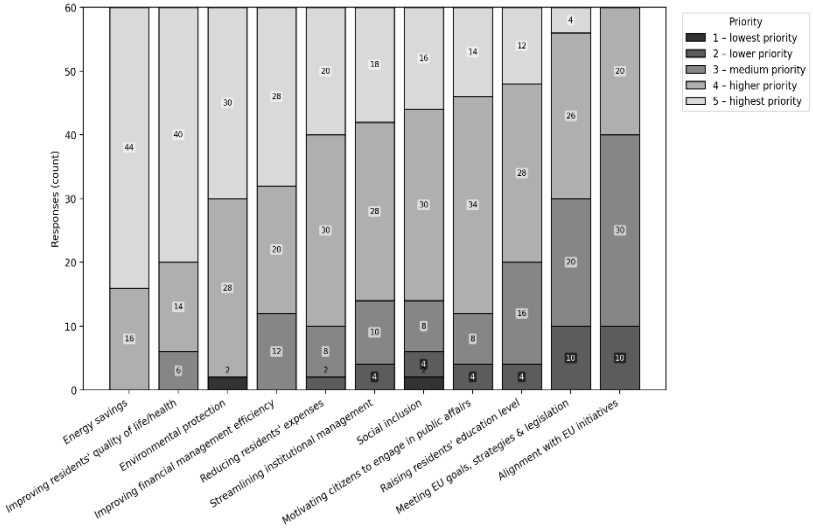



Figure 8.35

The weight of individual motivators related to the SMART concept.

Source: own research

The clearest “top-priority” leaders are Energy savings and Improving residents’ quality of life/health. Energy savings records 44/60 (73%) at the

highest tier and 16/60 (27%) at the higher tier, virtually no mid/low selections, signalling a dominant, unequivocal driver. Improving quality of life/health reaches 40/60 (67%) at the highest tier and another 14/60 (23%) at the higher tier, again leaving little room for medium/low responses. Both results point to an emphasis on direct, tangible benefits, cost and energy reduction on one hand, and citizen well-being on the other. Close behind, Environmental protection and Improving financial management efficiency are also strongly prioritized. Environmental protection concentrates almost entirely in the top two tiers 30/60 (50%) highest and 28/60 (47%) higher, with just 2/60 (3%) lowest; this pattern indicates a near-universal view that environmental goals are a high-stakes motivation rather than a "nice to have." Financial management efficiency shows a similarly robust profile, 28/60 (47%) highest, 20/60 (33%) higher, 12/60 (20%) medium, highlighting the importance of budgetary performance and measurable savings as a SMART driver. A second tier of motivators is anchored by Streamlining institutional management, Motivating citizens to engage in public affairs, Reducing residents' expenses, and Raising residents' education level. Institutional management is weighted toward "4 – higher" (28/60; 47%) with 18/60 (30%) "5 – highest"; the mix suggests respondents see organizational efficiency as crucial, though often a step below the most urgent outcomes (energy, quality of life). Citizen engagement concentrates at the higher end too, 34/60 (57%) higher and 14/60 (23%) highest, implying widespread recognition that participation is a key enabler of SMART impact, even if not always the single top priority. Reducing residents' expenses balances 30/60 (50%) higher and 20/60 (33%) highest, consistent with the fiscal lens present in other items.

Education level shows 28/60 (47%) higher and 12/60 (20%) highest, reflecting strong—if slightly less urgent—support for skills and human capital as foundations for SMART adoption.

By contrast, EU-oriented drivers are generally graded below the very top. Meeting EU goals, strategies & legislation distributes across 26/60 (43%) higher, 20/60 (33%) medium, and only 4/60 (7%) highest. Alignment with EU initiatives spreads 20/60 (33%) higher and 30/60 (50%) medium, with no "highest" selections at all. These responses suggest that while EU alignment and compliance are important, they are typically perceived as instrumental or contextual motivators—supporting frames rather than the most urgent reasons to act.

Social inclusion sits between the second tier and the EU-oriented items. It draws 30/60 (50%) higher and 16/60 (27%) highest, with modest medium/low tails; this underscores inclusion as an acknowledged high priority, even if it does not reach the "must-act-now" intensity of energy savings or health/quality-of-life improvements.

The results of the question on priorities for implementing SMART solutions in the city within individual areas are shown in Figure 8.36.

Across the portfolio, Energy, Environment, and Transport & mobility stand out as the strongest implementation priorities. Energy is overwhelmingly rated High with 48/60 (80%), followed by medium 10/60 (16.7%) and low 2/60 (3.3%), signalling clear alignment on projects that deliver measurable efficiency and savings. Environment mirrors this pattern, high 44/60 (73.3%), medium 14/60 (23.3%), no priority 2/60 (3.3%), suggesting that ecological goals are seen as near-imperatives rather than optional ambitions. Transport & mobility is also heavily prioritized high 38/60 (63.3%), medium 20/60 (33.3%), low 2/60 (3.3%), reflecting demand for traffic flow, safety, and mobility services as core SMART use cases.

Communication and Administration & governance shows a medium-heavy profile with substantial, though not dominant, high ratings. Communication concentrates at medium 32/60 (53.3%) with high 22/60

(36.7%) and low 6/60 (10%), indicating that cities widely acknowledge the importance of informing and engaging citizens, even if it often sits just below the most urgent infrastructure domains. Administration & governance follows a similar pattern medium 32/60 (53.3%), high 24/60 (40%), low 4/60 (6.7%) implying consistent attention to back-office and process modernization, but typically after the hard-impact areas have been addressed.

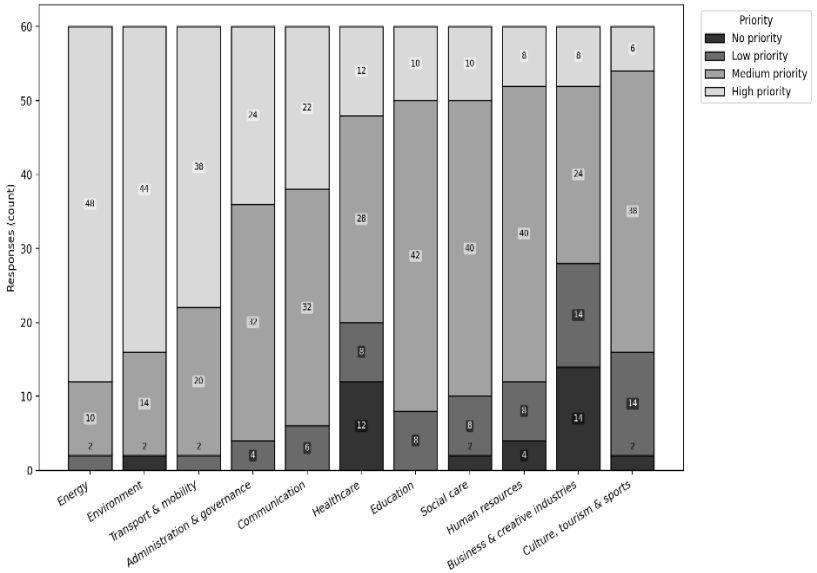



Figure 8.36

What is the priority for implementing SMART solutions in the city within individual areas?

Source: own research

People-centric services - Education, Social care, and Healthcare cluster around medium priority, with relatively modest high shares and some no priority signals. Education is predominantly medium 42/60 (70%) with

high 10/60 (16.7%) and low 8/60 (13.3%), pointing to steady, programmatic improvements rather than headline projects. Social care shows medium 40/60 (66.7%), high 10/60 (16.7%), low 8/60 (13.3%), and no priority 2/60 (3.3%), a similar "solid but not top-tier" stance. Healthcare is more mixed: medium 28/60 (46.7%), high 12/60 (20%), low 8/60 (13.3%), and a noteworthy no priority 12/60 (20%), indicating that, relative to other areas, health-related SMART initiatives are more unevenly prioritized across cities.

At the lower end of prioritization, Culture, tourism & sports, Business & creative industries, and Human resources attract fewer High ratings and more medium/low/no responses. Culture, tourism & sports registers medium 38/60 (63.3%), low 14/60 (23.3%), high 6/60 (10%), no priority 2/60 (3.3%), underscoring its supportive (rather than driving) role. Business & creative industries is split medium 24/60 (40%), low 14/60 (23.3%), no priority 14/60 (23.3%), high 8/60 (13.3%), suggesting more variability and, in many cases, no current prioritization. Human resources stays mostly medium 40/60 (66.7%) with high 8/60 (13.3%), low 8/60 (13.3%), no priority 4/60 (6.7%), pointing to steady but not urgent workforce-focused SMART initiatives.

In the following question (see Figure 8.37), we identified the attitude of municipalities towards the difficulty of implementing SMART elements/solutions from the perspective of resources (human/financial/other...).

Overall, cities most often rate Transport & mobility and Energy as the hardest domains to implement. In Transport & mobility, as many as 52 of 60 responses fall in the top two tiers, 28 "high difficulty" and 24 "very high difficulty" with only 2 "moderate" and 6 "no experience," indicating both widespread exposure and consistently high perceived demands on resources. Energy shows a similar pattern, leaning even more

toward the most demanding tier 34 “very high difficulty” plus 14 “high” (together 48/60) and very little in the middle (just 4 “moderate”) or the low end (8 “no experience”), which suggests that energy projects are not only a top priority in many cities but also resource-intensive to design, procure, finance, and operate.

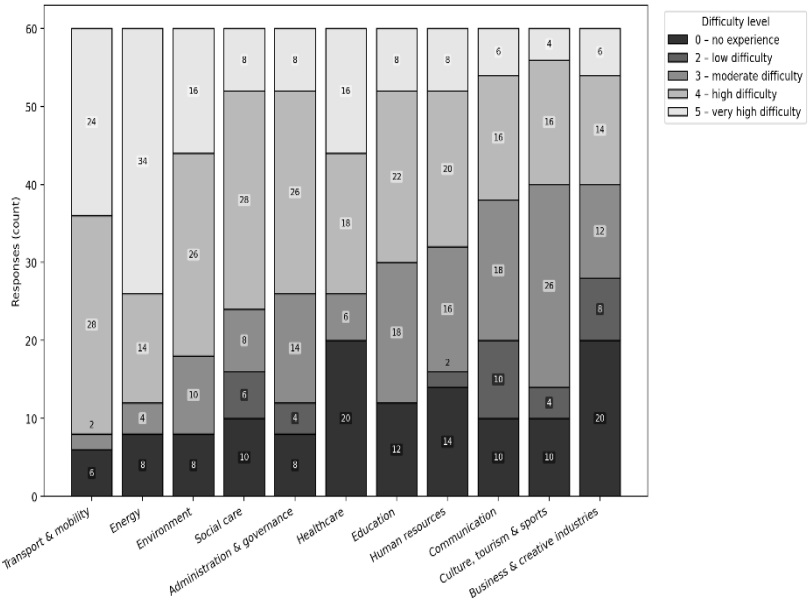



Figure 8.37

Complexity of implementing SMART elements/solutions in terms of resources (human/financial/other...).

Source: own research

A broader cluster Administration & governance, Social care, Environment, Healthcare, and Human resources also skews toward the upper difficulty tiers, though with more variation. Administration & governance records 26 “high” and 8 “very high,” while Social care has 28 “high” and

8 “very high,” both combining to roughly two-thirds of responses in 4–5, which points to the complexity of organizational change, process redesign, and cross-departmental coordination in these fields. Environment is likewise demanding 26 “high” and 16 “very high” consistent with the multi-project, multi-stakeholder nature of environmental programs. Healthcare shows 18 “high” and 16 “very high”, but notably also 20 “no experience,” suggesting that while many municipalities perceive health projects as resource-heavy, a sizeable share is not yet engaged. Human resources sits somewhat lower (20 “high,” 8 “very high,” 16 “moderate,” 14 “no experience”), reflecting steady but uneven maturity in workforce-related SMART initiatives.

Domains such as Education, Communication, Culture, tourism & sports, and Business & creative industries tend to concentrate more in the moderate band and show larger tails of “no experience” or “low difficulty,” implying more diverse starting points or narrower scopes. Education is centered around 18 “moderate” and 22 “high,” with 12 “no experience,” which hints at incremental, programmatic implementations rather than uniformly large, complex roll-outs. Communication spreads across 10 “no experience,” 10 “low,” 18 “moderate,” 16 “high,” and 6 “very high,” a balanced profile that likely mirrors the wide range of communication tools.

Culture, tourism & sports leans moderate (26) with 16 “high,” 10 “no experience,” and 4 “very high,” indicating that many cities are experimenting but fewer encounter systemic, high-intensity barriers here. Business & creative industries has the most “no experience” (20), and only 14 “high” and 6 “very high,” suggesting this area is less commonly pursued or remains early-stage in many municipalities.

Figure 8.38 shows the responses of individual cities to the question of what smart features have been implemented in their city. To understand the

overall prevalence of each solution, we split the lists and attributed the row's count to each item mentioned. We then grouped similar items into broader themes (e.g., all mentions of public/LED/"smart" street lighting were treated as one "Smart/public lighting" theme) etc. Because a single answer can touch multiple themes (e.g., "smart lighting" and "parking sensors" in the same line), category totals overlap and therefore sum to more than 100% of respondents. Totals are computed over 60 reported responses.

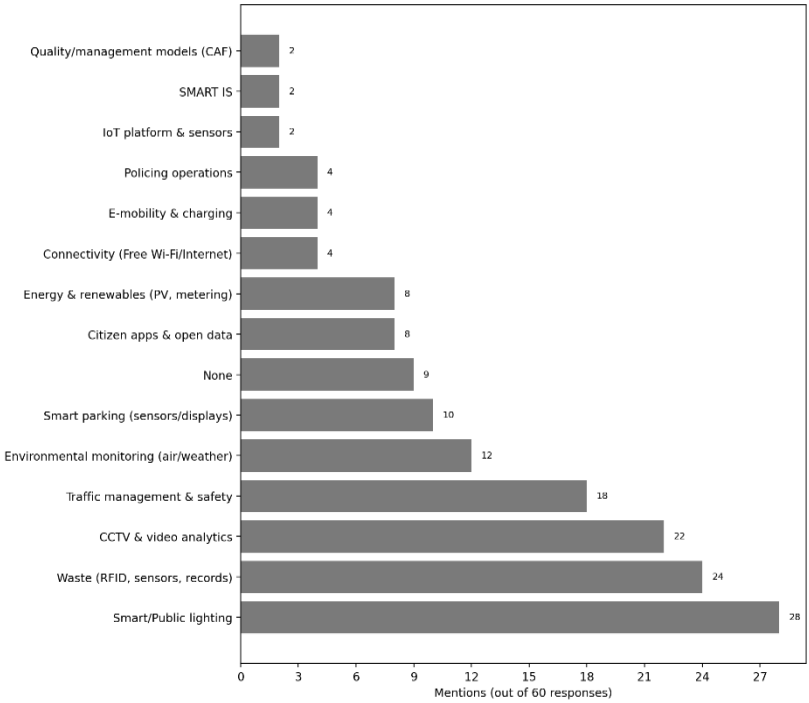



Figure 8.38

What specific SMART elements have been established in the city (list the most significant ones)

Source: own research

The data show Smart/Public lighting as the clear anchor, appearing in the equivalent of 28 out of 60 mentions (46.7%). This consolidated theme includes LED upgrades, smart control, modernization efforts, and the explicitly added "smart elements for public lighting," which together indicate that lighting remains the most widespread and mature smart-city investment in the sample. Close behind is Waste (RFID, sensors, records) at 24 mentions (40.0%).

The grouping spans RFID identification of bins, waste records, container fill-level sensing, and related instrumentation. This breadth suggests municipalities are not only digitizing waste service delivery but also building the data backbone (identification, telemetry) needed for route optimization and fairer billing models. CCTV & video analytics ranks third with 22 mentions (36.7%), now explicitly including "violation detection" per your mapping. Together with the lighting and waste clusters, the camera/analytics footprint underscores a pragmatic tilt toward public safety, deterrence, and evidence capture—capabilities that also feed traffic management and enforcement use-cases. Mobility-related themes are well represented, but diversified. Traffic management & safety (e.g., smart intersections, speed radars, pedestrian/vehicle detection) accounts for 18 mentions (30.0%), while the more specific Smart parking (sensors/displays) adds 10 mentions (16.7%). Read together, cities appear to be tackling both network-level efficiency (flows, safety) and demand-side frictions (finding a space) within the same strategic envelope. Environmental and digital-service layers are present at moderate levels. Environmental monitoring (air/weather) registers 12 mentions (20.0%), reflecting growing use of weather stations and air-quality probes. On the service side, Citizen apps & open data account for 8 mentions (13.3%), indicating movement beyond physical assets toward participatory tools and transparency. In parallel, Energy & renewables

(PV, metering) also post 8 mentions (13.3%), pointing to targeted deployments that complement the lighting investments with broader energy-efficiency or generation measures. A smaller, but meaningful, "long tail" rounds out the portfolio: Connectivity (Free Wi-Fi/Internet) at 4 mentions (6.7%), E-mobility & charging at 4 (6.7%), and Policing operations (e.g., operations centers) at 4 (6.7%). Foundational IoT platform & sensors and Quality/management models (CAF) each appear 2 times (3.3%), and a few entries remain idiosyncratic (e.g., "SMART IS" at 2 mentions; 3.3%)-likely local solutions or early pilots. Notably, 15% of the responses reported "None" (no SMART elements), emphasizing that a non-trivial share of municipalities are either pre-deployment or do not self-identify their initiatives as "SMART."

In the next question, respondents were asked to evaluate the impact of the SMART elements/solutions implemented in the city. The analysis of the collected responses reveals a differentiated perception of the impact of implemented SMART solutions. A total of 126 evaluations were aggregated across all response blocks. Within this dataset, 46 evaluations correspond to a positive impact, 44 evaluations indicate a neutral impact, and 36 evaluations report a very positive impact. These figures represent 36.5%, 34.9%, and 28.6% of the total respectively.

The distribution demonstrates that the majority of respondents perceive SMART implementations as beneficial. When combining positive and very positive assessments, 65.1% of all evaluations suggest that the introduction of SMART technologies has led to operational improvements. These improvements range from incremental process optimization to fundamental changes in municipal functioning. The proportion of very positive evaluations, amounting to 28.6%, indicates that in a significant subset of municipalities, SMART solutions have produced transformative effects,

likely through integrated digital platforms, automated monitoring, and data-driven decision-making.

Conversely, the presence of 34.9% neutral evaluations suggests that in many cases, the deployment of SMART elements has not substantially altered existing workflows. This outcome may be associated with limited implementation scope, pilot projects, or insufficient alignment between technological adoption and organizational processes. Such findings underscore the necessity of complementary measures, including process redesign and capacity building, to maximize the potential of SMART technologies.

The open question, "What benefits have resulted from the implementation of SMART elements/solutions?", provided the following findings. The qualitative analysis of the collected statements reveals several dominant dimensions of perceived benefits associated with the implementation of SMART solutions. The responses can be grouped into five overarching thematic areas: energy efficiency and sustainability, transparency and information accessibility, economic optimization, safety and security, and operational effectiveness.

First, energy efficiency and sustainability emerge as a primary objective. Multiple respondents emphasize reductions in energy consumption, cost savings in lighting systems, and the integration of renewable technologies such as electric vehicles and electric buses. These measures are linked to decreased carbon dioxide emissions, improved air quality, and extended building life cycles, collectively contributing to environmental sustainability and municipal energy self-sufficiency.

Second, transparency and accessibility of information represent a significant improvement. The deployment of sensors and digital platforms has enabled real-time data acquisition on waste production, energy

consumption, and traffic conditions. This availability of accurate and timely information supports evidence-based decision-making and enhances managerial control. However, some responses indicate limitations in public access to environmental data, suggesting that open-data strategies remain an area for further development.

Third, economic optimization is consistently highlighted. Respondents report financial savings in public lighting, waste collection, and traffic management. Technologies such as RFID-based waste container identification and route optimization systems have contributed to cost reductions and improved resource allocation. These outcomes demonstrate the potential of SMART solutions to deliver measurable economic benefits when integrated into core municipal processes.

Fourth, safety and security constitute a recurring theme. Enhanced street lighting, expanded camera coverage, and improved monitoring capabilities have collectively increased perceived public safety. The establishment of operational centers and advanced video analytics has facilitated faster incident resolution and strengthened law enforcement effectiveness.

In the last question, respondents could identify what barriers they encountered when implementing SMART elements/solutions (see Figure 8.39). The question was closed, and they could only select one barrier for each area.

In the Financial domain, evidence points to a pronounced constraint on the adoption of SMART solutions. Only 16.7% of responses indicate no issue, while 30.0% report limited implementation and 26.7% report prevented implementation, together implying that 56.7% perceive finance as limiting or outright blocking implementation. A further 23.3% indicate barriers eliminated by corrective action and 3.3% removed by corrective action, suggesting that while targeted remedie s can help, financial frictions

remain structurally significant for a large share of respondents.

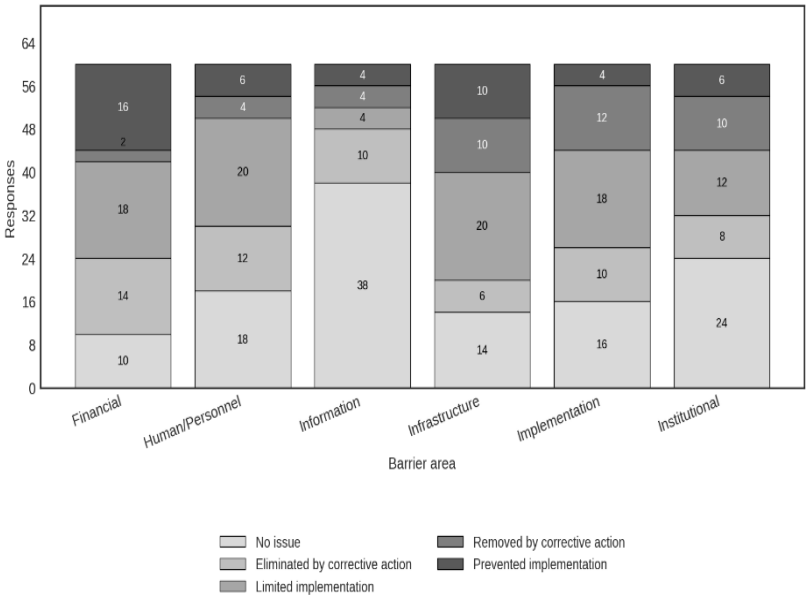



Figure 8.39

What barriers were identified in the implementation of the above SMART elements/solutions?

Source: own research

The Human/Personnel area exhibits a more balanced pattern. No issue accounts for 30.0%, whereas imited implementation is the single largest category at 33.3%. corrective actions play a non-trivial role—20.0% eliminated by corrective action and 6.7% removed by corrective action—and complete blockage is comparatively infrequent at 10.0% (prevented implementation). Together, these figures indicate that human-capacity constraints are common but often tractable, with many organizations able to mitigate issues once identified.

By contrast, Information barriers appear least problematic. Nearly two-thirds (63.3%) report no issue. The remaining responses are dispersed thinly: 16.7% eliminated by corrective action, and 6.7% each for limited implementation, removed by corrective action, and prevented implementation. This distribution suggests that access to or processing of information, while occasionally challenging, is usually either already adequate or readily corrected without persistent residual effects on deployment.

Infrastructure emerges as a substantive impediment. Only 23.3% indicate no issue. One-third (33.3%) report limited implementation, and meaningful shares denote more severe frictions: 16.7% removed by corrective action and 16.7% prevented implementation. Although 10.0% say issues were eliminated by corrective action, the overall profile (with 76.7% encountering some form of barrier) underscores that physical/technical infrastructure frequently constrains the realization of SMART elements.

The Implementation domain shows a mixed, process-oriented constraint landscape. No issue stands at 26.7%, while limited implementation reaches 30.0%. Importantly, remedial pathways are prominent: 16.7% eliminated by corrective action and 20.0% removed by corrective action together account for 36.7%, indicating that many implementation hurdles are manageable with targeted solutions. Still, 6.7% report prevented implementation, signifying a residual hard barrier for a minority of cases.

Finally, Institutional factors are relatively less obstructive but not negligible. No issue is highest here at 40.0%. Yet 20.0% report limited implementation, 16.7% removed by corrective action, 13.3% eliminated by corrective action, and 10.0% prevented implementation.

## 8.2 Summary

The research evaluates the adoption and implementation of SMART solutions in Slovak municipalities through a questionnaire survey conducted between January and September 2025. The survey targeted 100 municipalities and achieved a 60% response rate, with 60 valid questionnaires analyzed. The study aligns with the objectives of the 2030 Agenda for Sustainable Development and explores strategic priorities, implemented activities, barriers, funding mechanisms, and perceived impacts of SMART initiatives. The questionnaire comprised 17 questions, including closed and open formats, focusing on priorities, operational activities, implementation status, financial resources, motivators, and barriers. Responses were analyzed quantitatively and qualitatively to capture both numerical trends and thematic insights.

Respondents overwhelmingly rated SMART elements as highly important across all strategic areas, with citizen quality of life and city development strategy receiving the strongest emphasis and negligible support for low or no priority categories. Regional and EU strategies were considered important but less critical compared to urban and citizen-focused initiatives. Municipalities most frequently integrate SMART concepts into strategic documents such as the Program of Economic and Social Development, while communication and citizen engagement rank high, followed by practical implementation through city projects. Activities related to monitoring and evaluation remain minimal, indicating a gap in systematic performance assessment. Public lighting modernization and waste management dominate current SMART deployments, each accounting for 13.8% of reported activities, followed by security and surveillance at 11.5%. Digitalization, traffic control, and IoT-based solutions appear but at lower frequencies, and emerging areas such as e-mobility and connectivity remain marginal. Future

plans emphasize infrastructure and efficiency, with waste management, energy efficiency, parking systems, and digitalization each representing approximately 10.6% of planned activities. Transport monitoring and strategic planning also feature prominently, while e-mobility and connectivity remain niche priorities.

Most municipalities are in early stages of implementation, with 36.7% reporting partial implementation and 33.3% initial phase, while only 6.7% have reached improvement or maintenance stages, confirming that SMART adoption is progressing but not yet mature. Financial constraints are a critical challenge, as nearly 38.5% of activities rely solely on municipal budgets and 37.8% report no funding. EU and grant resources play a supplementary role and are rarely used independently. Strategic document preparation and citizen communication are primarily funded from municipal budgets, whereas evaluation and feedback mechanisms are largely unfunded. Energy savings and improving residents' quality of life dominate motivators, each rated as highest priority by over two-thirds of respondents, followed by environmental protection and financial management efficiency. EU compliance and alignment rank lower, suggesting that local benefits outweigh external obligations. Implementation priorities concentrate on energy, environment, and transport and mobility, which are rated high by 80%, 73.3%, and 63.3% of respondents respectively. Communication and governance are medium-priority domains, while education, social care, and healthcare show moderate emphasis. Culture, tourism, and creative industries attract the least attention.

Transport and mobility and energy projects are perceived as most resource-intensive, with over 80% rating them high or very high in complexity. Financial barriers are the most critical, as 56.7% of municipalities report limited or prevented implementation due to funding

issues. Infrastructure barriers affect 76.7% of respondents, while human resources and institutional factors are less severe but still notable. Information-related barriers are minimal, with 63.3% reporting no issue. Overall, 65.1% of evaluations indicate positive or very positive impacts of SMART solutions, suggesting operational improvements and, in some cases, transformative effects. Reported benefits cluster around five themes: energy efficiency and sustainability, transparency and data accessibility, economic optimization, safety and security, and operational effectiveness. These findings reveal strong strategic commitment to SMART initiatives, particularly in energy, environment, and mobility. However, implementation remains uneven, constrained by financial and infrastructural barriers. While municipalities recognize the importance of citizen engagement and governance, these areas often lag behind hard infrastructure projects. Limited funding for evaluation and feedback mechanisms suggests a need for systemic improvements in monitoring and performance assessment. The dominance of local motivators over EU compliance underscores the importance of framing SMART adoption in terms of tangible benefits for residents and operational efficiency. SMART solutions are widely perceived as essential for sustainable urban development in Slovakia. Despite early-stage implementation and persistent resource constraints, municipalities demonstrate clear priorities and a willingness to integrate SMART concepts into strategic planning. To accelerate progress, targeted financial support, capacity building, and robust evaluation frameworks are recommended.

# CONCLUSION

The scientific monograph Smart Cities and Sustainable Regional Development presents the results of an extensive analysis of theoretical foundations, developmental stages, and case studies that clearly confirm the importance and relevance of the Smart City phenomenon in the context of regional development. Demonstrating the positive effects of smart solutions in the areas of administration, economy, mobility, housing, waste management, and energy highlights their transformative potential in shaping inclusive, resilient, and sustainable cities.

The scientific monograph systematically elaborates on the individual dimensions of the Smart City concept, from technological foundations and participatory management to environmental and social aspects. The authors rely on an interdisciplinary approach, combining knowledge from public administration, economics, and digital technologies. Research findings in the areas of smart governance, trust-based economics, smart mobility, and the circular economy show that the application of smart solutions has significant benefits and contributes to the development of local economies, improving the quality of life of residents, and strengthening social cohesion.

The scientific monograph provides a multidimensional view of the Smart City issue, i.e., from the historical development of the concept through its current paradigms to the prediction of future trends. In the context of Agenda 2030, Smart City is interpreted as a practical tool for achieving sustainable development goals, particularly in the areas of inclusion, climate resilience, digital sovereignty, and transparent decision-making.

Case studies from European cities such as Amsterdam, Oslo, Hamburg, Vienna, and Bratislava illustrate the diversity of approaches, emphasizing the

importance of strategic planning, open data, cooperation, and citizen participation.

The Smart City concept can therefore be seen as an essential part of modern local government, creating resilient and prosperous regions. Its potential lies in empowering local communities, improving the quality of public services, and promoting environmental and economic sustainability.

The authors of the scientific monograph express their desire for a full understanding of the Smart City phenomenon as a comprehensive framework that goes beyond technological innovation and becomes a tool for democratizing decision-making processes, strengthening community life, and strategic planning for the benefit of current and future generations. We believe that this publication will contribute to the development of professional discourse on the future of cities in the digital era and will be an inspiration for public policy makers, experts, local governments, and civil society.

Authors

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