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Grzegorz KINELSKI[1]

Smart-city trends in the environment of sustainability as support for decarbonization processes

ABSTRACT: The smart-city concept refers to a city that uses information and communication technologies to increase the interactivity and efficiency of urban infrastructure and its components, as well as raising awareness among residents of, for example, such socially important issues as energy efficiency and decarbonization. The current priorities and strategic goals of cities and metropolitan areas include climate protection, the reduction of pollution caused by the use of means of transport and heat or energy sources. The development of technology and the evolving smart-city concept are in line with the more efficient use of resources, global demographic trends, and ongoing urbanization processes. This results from the evolving potential of cities that the new information and communication technologies (ICTs) have set in motion. A change in the way cities function is a part of the concept of sustainable development, which involves the thoughtful use of resources in such a way that they are sufficient to not only ensure the well-being of the present generation but to also meet the needs of the future. Particularly important is the principle of sustainable development, which involves the greatest possible synergy between people and the world around them. Therefore, the essence of the idea of sustainable development is the pursuit of the well-being of society while maintaining the integrity of the ecosystem. Studies carried out among inhabitants of cities show that according to their understanding of the smart-city concept, the technological element is as important as the fact that the city is resident-friendly, smartly managed, and well organized, and the entities needed are always in the right place and at the right time. The purpose of this study is to analyze the innovation

✉ Corresponding Author: Grzegorz Kinelski; e-mail: grzegorz.kinelski@gmail.com

[1] Management, WSB University, Poland; ORCID iD: 0000-0002-5768-463X; e-mail: grzegorz.kinelski@gmail.com

potential of selected cities of a large metropolis in terms of the smart city concept and 4T capitals. The subject is related to the search by city authorities for new models and tools to shape sustainable development in order to improve their residents' access to municipal services and amenities, as well as to increase their influence on the future of their cities in such difficult ongoing processes as decarbonization. The main objective of the study was to identify how the authorities of the selected cities incorporate smart-city and 4T-capital topics into local policies to achieve decarbonization goals. The study was based on surveys of residents and municipal employees and on an analysis of local documents and environmental data of pollutions.

Keywords: urban governance, smart city, sustainable development, decarbonization, 4T potentials

Introduction

Smart cities are usually distinguished by a large number of projects and programs related to the application of smart technologies. The main challenge faced by such dynamically developing organizations as cities is to create and, most importantly, implement strategies that contribute to attracting and retaining entities that initiate smart growth in the city. Such entities include residents with high skills and socioeconomic competences, businesses and institutions that create and implement knowledge, investors who instill new models of business activity, as well as visitors who contribute to the creation of personal relations between the city's community and its surroundings. Cities following the path of smart growth must also face the challenge of building a new quality of life for different social groups. It is necessary to constantly study the correlation between the transformation of the quality of life and potential 4T resources (Florida 2012; Jourdan 2008). The author argues in his research that there is a nexus of factors from the areas of tolerant community, creative professions, and high level of technological development that dynamizes urban development. Metropolises with high ratios trust, tolerance, talent, and technology attract highly skilled and creative workers, people from the world of culture and art, and investors. Such places, thanks to such potential, become the best developing cities that successfully face the very quickly changing reality (Prokopowicz 2016).

Expectations are changing, for example, with regards to the procurement of energy, the speed of RES development, the innovation of energy projects, changes in source technologies, and energy storage (Jasiński et al. 2021; Kaszyński et al. 2021; Saługa et al. 2021). This is done through the introduction of new technologies and processes in the energy sector, the renewable energy sector, from consumers to prosumers (Czarnecka 2014), including cognitive technologies, and the continuous improvement of efficiency and competitiveness (Malec et al. 2021). If the above changes are made with care for the environment and the conscious use of resources, we can consider this as smart and sustainable development at the same time.

Sustainable development is currently the best tool for achieving specific economic or investment goals, with particular attention to the environment in which we work and our impact

upon it. Tools to support sustainable development include the current phase of innovation and invention, the implementation of the smart-city concept (Szczepańska-Woszczyna and Kurowska-Pysz 2016), the fourth industrial revolution, and the "Digital Economy" (Borowiecki et al. 2021; Kinelski 2019; Makieła Z. 2015).

The smart-city concept is a response to global demographic trends, ongoing urbanization processes and the pursuit of sustainable development (Szołtysek 2017; Zygiaris 2013). As a result of demographic trends, global warming, and turmoil in the global economy, cities provide a space for creative social experimentation and problem solving in the contemporary world (Korneluk et al. 2019). It is necessary to start with the formulation of challenges and the identification of priorities for their optimal solution in order to build smart cities (Fojud 2015; Korneluk et al. 2019; Zygiaris 2013). This term has many definitions in the literature, but most researchers identify the term with a city with a development strategy that focuses on creativity, openness to innovation and flexibility, and understood as the ability to quickly adapt to external and internal conditions (Giffinger et al. 2007). In order to find a single definition of the smart-city concept, six key areas have been adopted to which cities aspiring to be smart should refer. These are:

- Economy – Smart Economy;
- Communications and Transportation – Smart Mobility;
- Environment – Smart Environment, with key strategies as decarbonization;
- Population and Residents – Smart People;
- Quality of Life – Smart Living;
- Governance – Smart Governance.

To ensure the correct formulation and understanding of the smart-city concept, it is associated with the concept of innovation, not only with technology. However, in the processes of governance of a smart city, new technologies play an important role and can help city authorities cope with the challenges of today arising from the growing urban population and the increasing digitization requirements (Muangmee et al. 2021; Mucha-Kuś et al. 2021; Przybyłowski 2020).

The smart-city concept is a new approach to city management. This is the creation of a new system for functioning of cities in which the local government, while defining public tasks and choosing the form of their implementation, also: sets the quality standards and the intended outcomes for the services provided; is interested not only in the continuity of the services, but also in their economic efficiency (Trąpczyński et al. 2019); takes into account the development of new technologies, including the implementation of environmentally friendly and energy-efficient solutions, which allow for ensuring energy security as well as sustainable development (Kinelski 2020; Szczech-Pietkiewicz 2015; Wójcik-Jurkiewicz et al. 2021).

The paper presents the development of selected cities of the Upper Silesian – Zagłębie Metropolis in terms of the smart-city concept and 4T capitals. The subject discussed herein is also related to the search by city authorities for new models and tools to shape sustainable development in order to improve their residents' access to municipal services and amenities as well as to increase their influence on the future of their cities and networking, as strategic objectives (Czakon 2011; Jedynak et al. 2021). The main objective of the study was to identify how the authorities of the selected cities incorporate smart-city and 4T-capital topics into local policies.

The conclusions and recommendations were based mainly on the results of surveys conducted among residents and the analysis of local documents supplemented by direct interviews with local managers and participatory observation.

The Upper Silesian – Zagłębie Metropolis, was established as the first local government institution of this kind in Poland. The metropolis integrates and coordinates the cooperation of forty-one cities and municipalities located in the central part of the Silesian province. The scope of its tasks is defined in a special law. One of the tasks is socio-economic development and therefore the improvement of the quality and the comfort of life of citizens. This goal can be achieved by, among other strategies, implementing the smart-city concept, which can actually improve the functioning of residents in the urban space. Smart city aims to solve various urban problems, including limited access to or a lack of certain public services, traffic jams, overly rapid development, limited land availability, degradation of the environment, and others with the use of ICT. A smart city is designed to be a creative, more sustainable city where the quality of life is improved, the environment is more friendly, and the prospects for economic development are stronger (Lee et al. 2014).

1. Review of the literature on the smart-city concept

The smart-city concept emerged as a result of evolutionary research on smart urban environments (Caragliu et al. 2006; Katz and Bradley 2013). The term "smart city" is understood as a certain intellectual ability that refers to the innovative socio-technical and socio-economic aspects of development (Szołtysek 2017; Mucha-Kuś et al. 2019). It is distinguished by six dimensions (Toppeta 2014): smart economy, smart mobility, smart environment, smart people, smart life, and smart governance.

Boyd Cohen and N. Komninos proposed three phases of smart-city development identified as Smart City 1.0, Smart City 2.0, and Smart City 3.0. (Boyd Cohen 2012; Komninos 2008, 2020) The proposed phases are not exhaustive, as we are currently seeing the formation of the next phase, Smart City 4.0, inspired by the concept of economy 4.0 (Makieła Z.J. 2014; Morawski 2021; Stuss et al. 2020).

- Smart City 1.0 refers to smart cities in their earliest stages of development. The use of modern technology is initiated by ICT companies. Such cities implement different solutions, regardless of whether they are needed by these cities or not. A good example is the city of Songdo in South Korea. This emerging modern ubiquitous city is the largest private development in the world. It should become a business center comparable to Shanghai, Hong Kong, Kuala Lumpur, and Singapore (Al-Gasawneh et al. 2021; Hussain et al. 2021).
- Smart City 2.0 is the development phase of smart cities where the dominant role is played by public administration. The use of modern technologies is initiated by local authorities and the introduction of new solutions is aimed at improving the quality of life of residents. Ac-

cording to the smart-city researcher, Boyd Cohen, today, the majority of cities implementing smart-city projects are in the 2.0 generation (Azkuna 2012; Lee et al. 2014; Zygiaris 2013).

- Smart City 3.0 is a new approach to creating smart cities that has been observed since 2015. Many influential modern cities are opening up to the active approach of their citizens in the creation of further development. The role of local authorities is to focus on creating spaces and opportunities to harness the diverse potential of their residents (Świetlikowski 2016; Sześciło 2015). This includes both encouraging citizens to use modern technologies (e.g. through educational projects for the digitally excluded persons) and enabling them to create their own technological solutions (e.g. through open data).

Although Smart City 3.0 still refers to the use of modern technology to improve the quality of life in cities, its area of interest is expanding and, in addition to projects specific to the second generation, includes social, equality, educational, and environmental issues. Smart City 3.0 fits into the increasingly popular sharing economy (Han 2019; Kinelski 2018; Wójcik-Jurkiewicz et al. 2021). This often requires the courage of city authorities to accept the growing position of citizens. However, it is not only a mental layer (authorities – citizens), above all, the communication layer that must change. Dialogue, mediation, and deliberation are beginning to play a dominant role. This rests on Neo-Weberism and the Co-Governance Theory described in the literature. (Dunn and Miller 2007; Heugens 2005; Patwardhan et al. 2018; Ruacan 2021).

With reference to the practice of local government, an interesting evolution of the approach to the smart-city concept is presented by the authors of the Human Smart City guide for local governments who, according to B. Cohen, distinguish three levels of the development of Smart Cities. This concept is shown in Fig. 1 below, which is expanded to include the fourth level discussed herein, i.e. the Smart City 4.0 concept.

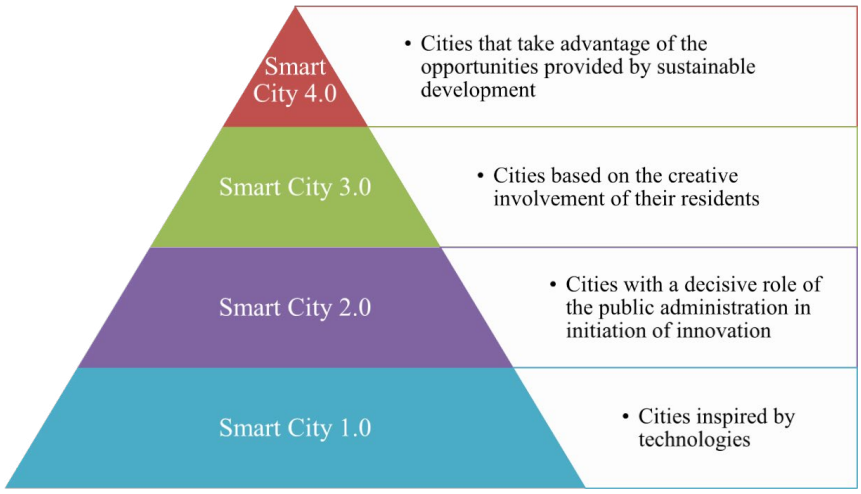

Fig. 1. Levels of development of smart cities
Source: prepared by the author based on (Korneluk et al. 2019; Makieła Z. 2015; Makieła Z.J. 2014)

Rys. 1. Poziomy rozwoju *smart city*

The challenge that local governments currently face is, first and foremost, to base development on the creative involvement of residents. In a third-generation smart city, residents are beginning to participate in the creation of their cities. This can be seen when a significant role in urban initiatives is played by social projects related to equality, social inclusion, affordable housing, decarbonization, etc. (Korneluk et al. 2019).

The smart-city concept, based on the 4T (technology, trust, talent, and tolerance) capitals theory, aims to solve various urban problems, including limited access to or a lack of some public services, the problem of mobility and transport, overly fast development, limited land availability, environmental degradation, and others (Åhman et al. 2017; Svensson et al. 2020). As a sustainable city, a smart city must be designed as a creative place. Such a city understands its residents and, as a result, the quality of life improves and the environment is more friendly. In such an urban, economic space, the prospects for economic development are much stronger. This concept includes such potentials as talent, technology, tolerance, and trust. This concept was formulated by the American researcher, Richard Florida, and described in further studies (Florida 2003; Hospers and Van Dalm 2005; Vergara Perucich 2019). The author argues that there is a nexus of factors from the areas of the tolerant community, creative professions, and the high level of technological development that dynamizes urban development. Metropolises with high ratios of trust, tolerance, talent, and technology attract highly skilled and creative workers, people from the world of culture and art, and investors. Such places become the best developing cities because of such potential. Researchers have used various concepts referring to urban development. The multitude include: smart city, 4T theory, sustainable city, sharing economy city, innovative city and learning city. Relations between those concepts are outlined in Figure 2.

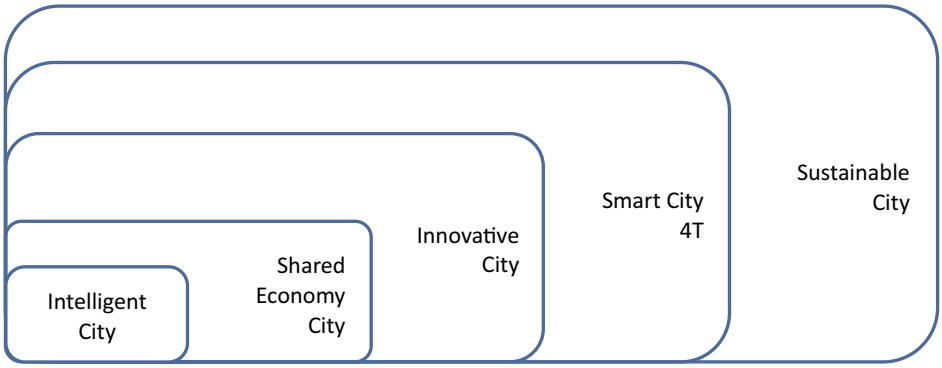

Fig. 2. Relations between different kinds of smart cities
Source: prepared by the author

Rys. 2. Relacje między różnymi formami *smart city*

There is no doubt that every modern city is a complex ecosystem with many components that include all things that connect people, the environment and technology. Certainly, what constitutes a strategic differentiating feature of dynamically developing cities is a smart urban

infrastructure that serves both residents and the municipal administration (Dyduch and Bratnicka 2014; Krzakiewicz and Cyfert 2019). When creating Smart City 4.0, one must always take into account an entire complex network of interconnections that provide real benefits. The formation of Smart City 4.0 is strongly correlated with successive industrial revolutions dominated by robots, artificial intelligence, nanotechnology, the internet of things and autonomous vehicles. Profound technological changes (Al-Fuqaha et al. 2015; Clark 2007; Hinojosa et al. 2010; Rutten and Gelissen 2008) with large social and economic impact on cities and on the natural environment are a part of the process of sustainable development, which sets high standards for residents (Kinelski et al. 2021; Piontek 2019).

The smart-city complex implemented in cities should be based on a solidly thought-out and properly implemented smart urban infrastructure which provides the basis for the further development of other potentials. In the simplest terms, the idea is to use an integrated internet of things (Adepoju 2022; Motlagh et al. 2020; Nižetić et al. 2019) (IoT) infrastructure to increase the efficiency of city services and companies and ultimately improve the lives of residents while taking care of the environment. Solutions that are based on these solid foundations, are properly implemented and make up the overall smart-city concept also contribute to more efficient urban investments and more sustainable city development. This in turn translates into changes for all stakeholders of the city as an organization (Pabian et al. 2021; Stefańska and Bilińska-Reformat 2020; Zanella et al. 2014).

Common, central, and convenient smart IoT systems have been implemented and are already functioning in Polish cities. These include a range of essential services for every resident. Examples include water supply and the remote metering of water consumption, energy-efficient LED street lighting with management systems, municipal bicycle systems, smart monitoring and parking space management, waste collection and disposal, remote electricity metering for public entities, and renewable energy systems (Kaszyński et al. 2021; Zamasz et al. 2021). Other examples are air- and water-quality sensors and the so-called smart benches that, placed in urban spaces, provide Internet access and the ability to charge mobile devices, smartphones, and tablets and use energy from photovoltaic panels.

A high level of integrity in these systems, as well as their effectiveness and utility, can be achieved through consistent actions of municipal authorities, openness, and agency. It is extremely important to have an open, good working relationship with providers of smart systems who have the right knowledge, experience, and technology. Researchers recognize that the first wave of Smart Cities 1.0 was driven by technology. Smart Cities 2.0 brought the recognition that technology must serve people and Smart Cities 3.0 was the push toward "hyper-connectivity," which ESI ThoughtLab focused on in its 2019 research. This hyperconnectivity was not only about technology, but also about citizen involvement and partnerships. Smart Cities 4.0 are still hyper-connected and leverage technology, data, and citizen involvement, but use them to achieve sustainability goals (Makieła Z. 2015; Makieła Z.J. 2014). "We believe this is the way cities are headed. It is not enough to be smart; you must also be sustainable" (*ESI Thoughtlab Takes Thought Leadership to the next Level*, 2018).

Sustainable development goals are the priority of the future. Researchers from ESI ThoughtLab found that city mayors use the lessons learned during the pandemic to chart a path toward achieving

sustainability goals. They reported that they do the most work on sustainability goals related to people, including no poverty (91% of cities), good health and well-being (89%), decent jobs (86%), and good education (86%). Survey respondents also identified obstacles to the achievement of sustainability goals over the next three years, including complex policies and regulations (52% of cities), finding the right partner or supplier (50%), and managing data security and privacy (44%).

Furthermore, city leaders can use ESI ThoughtLab's research as a roadmap to becoming Cities 4.0. They can also take the four steps that Cities 4.0 take to advance their SDG (Sustainable Development Goal) programs:

1) regularly monitoring and evaluating SDG efforts;

2) ensuring broad support for SDG programs across the government;

3) designating a department to take the lead on the SDGs;

4) conducting a voluntary local review of the progress made toward the achievement of the sustainable development goals.

Cities are increasingly complex and multidimensional urban systems that are of key importance to human life on our planet. Their importance is evidenced by the worldwide recognition that we are living in an era of urbanization that approaches planetary one (Popescu 2020).

In addition to advanced technology, there is a growing importance of soft capabilities, which include technology, talent, tolerance, and trust. The smart-city concept is based on four pillars – the 4T potentials of technology, talent, tolerance, and trust; the level of their advancement in a city determines its intelligence, entrepreneurship, and innovation (Stuss 2021). An advanced share of the 4Ts in smart city governance is a determinant of the city's residents' quality of life and its competitive position in the metropolis.

Cities are prioritizing their urban innovation systems, starting from the traditional urban character to an innovative "green," "smart," and "open" character, and striving for environmental and social sustainability (Zygiaris 2013).

The idea of a smart city as an innovative city – as well as an entrepreneurial, attractive, and competitive city that cares for creative individuals – refers to the current of research that concludes that the greatest potential resource that conditions economic development is knowledge, and that innovation (being an emanation of knowledge) is the main driver of growth and economic development (Bartkowiak A. and Bartkowiak P. 2012; P. Bartkowiak P. et al. 2019; Krzakiewicz and Bartkowiak P. 2021). The effect of implementation of innovation is modernization, increased efficiency and competitiveness, and consequently the amount of income generated (Makieła Z.J. 2014). However, undertaking an analysis of the determinants and benefits of a pro-innovative city development strategy requires, first of all, defining the substantive scope of the term "innovation," which goes beyond the context of urban studies.

Poland is not only using coal for much of its energy mix but also exports it. The decarbonization of the energy sector is therefore closely linked to the linear reduction of the coal sector – the consumption of coal in power plants and houses (Hildingsson et al. 2019). GZM Metropoly faces unique challenges in its energy transition due to the extreme dependence on coal. Nevertheless, many countries are already going through or will undertake the transition to a low-carbon economy. Decarbonization is based on better energy efficiency and the supply of zero-emission clean

electricity instead of fossil fuel-derived electricity, where possible (Drożdż et al. 2021). The necessary technologies already exist and are becoming increasingly available. There could also be considerable additional benefits, such as cleaner local environments and economic modernization. However, making the transition to low-carbon technology is a policy challenge for cities and metropolises (Labanca et al. 2020; Victoria et al. 2020).

Overall, there is a shift away from coal and ultimately also from gas and oil. De-carbonization further fosters economic growth and more sustainable forms of economic growth and energy transformation in all domestic studies (Hübler and Löschel 2013).

In recent years, numerous programs have emerged to reduce the economic in-equality between countries and overcome the ecological crisis, this helps for cities on the way to be sustainable (Oyewunmi et al. 2018).

2. Methodology for studying city potentials

Based on J. Creswell's (Creswell 2013) research methodology, the following research problems were formulated:

1) to identify the innovative potential of a learning city and to diagnose the innovative potential of cities in the context of entrepreneurship, innovativeness of residents, and entities that support innovativeness;

2) to identify results of decarbonization in GZM areas;

3) to identify, acquire, and develop smart-city areas.

The process of research show Figure 3.

The main research tool was a survey method – a questionnaire-based study:

- measuring perceptions of the innovation of cities by residents and officials;
- measuring the development strategy in the office (Denford 2013b);
- checking and analyzing the data of air pollution in GZM.

The questionnaire contained closed questions with pre-coded response options. This was due to the previous analyses of the problem of the innovative potential of a city or municipality (Beechler and Woodward 2009; Cheese 2008; House of Skills 2016). Similarly, the list of questions was strictly based on the literature studies and diagnoses of other research tools conducted earlier so that it could not influence the type of answers obtained and to minimize bias in the results (KELLEY 2003). The choice of the survey method is due to the fact that a questionnaire -based study enables a quantitative description of specific aspects of smart city governance in the Upper Silesian – Zagłębie Metropolis, in a selected research group comprising cities located in the metropolis. The questionnaire-based method also allowed us to conduct research and obtain information that would otherwise be difficult to measure using observational techniques. The aims of the statistical (questionnaire) study included finding out the opinions of residents and employees of offices on the evaluation of the city's innovativeness, the quality of life in the city,

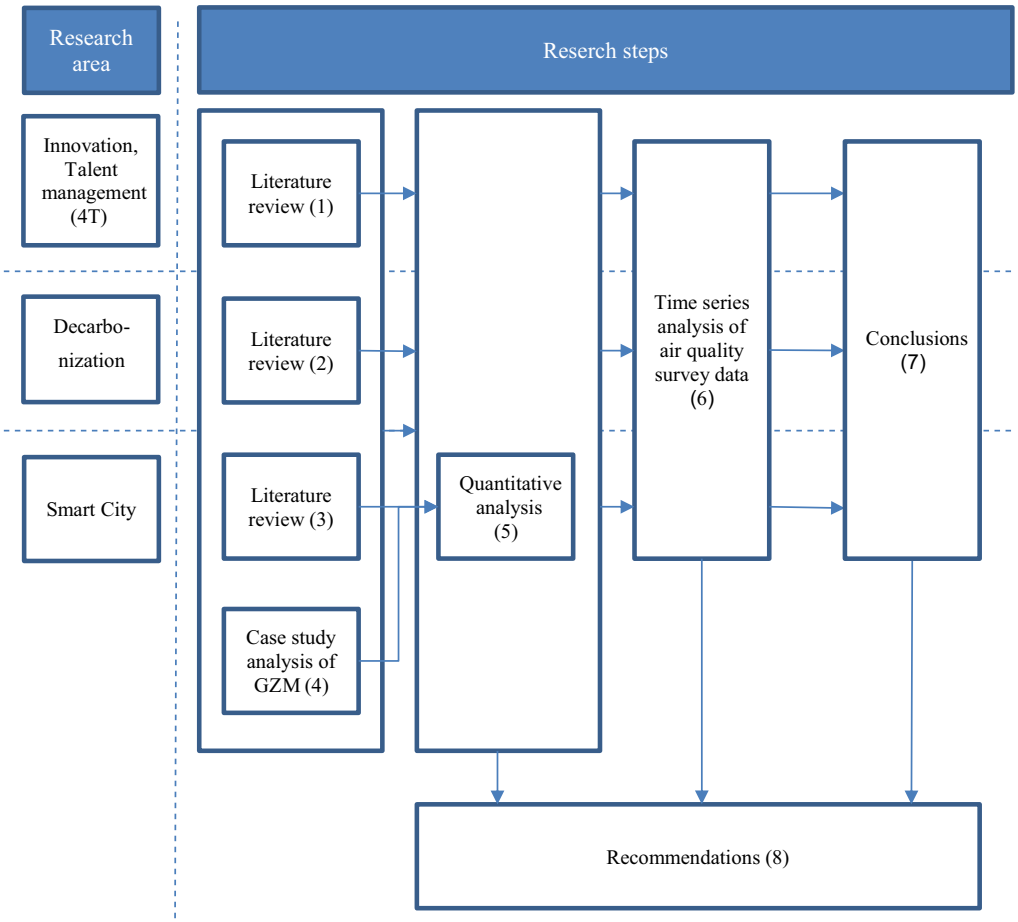

Fig. 3. Research process.
Source: prepared by the author

Rys. 3. Proces badawczy

the quality of transport, and the development of cities. The study was conducted using the CATI method and the number of residents who participated in the study was N = 600. The sample for the study was a quota and a random sample. The population characteristics that were considered for the sample were location, gender, age, and the education of the respondents.

A complementary research method was targeted interviews based on the approach proposed by Hennink et al. (2020) and Charmaz K. (2014).

They made it possible to assess:

- the level of innovation of cities and innovation support entities;
- the tools for identification of learning among office employees.

Adoption of the above research strategy made it possible to attempt to enrich and further develop both theory and practice. Targeted interviews were conducted with the management of

the cities studied. The interviews were conducted with the employees of the Upper Silesian – Zagłębie Metropolis Management Board. In addition, an analysis of source materials in the form of the strategic and program documents of the individual municipalities in question was conducted. This research method made it possible to determine the characteristics of and evaluate these strategic documents in the context of 4T capitals and the Smart City concept.

The sequence of diagnostic and analytical process based on the results of the study also leads to the recognition of the meaning of the smart-city concept itself through smart governance perceived from the standpoint of both its essence and its practical manifestations, all the way to good practices and projects along with expectations in terms of their guidance and implementation. The whole process is analyzed against the background of project management in the Upper Silesian – Zagłębie Metropolis. A synthesis of this approach is shown in Figure 4 below.

Fig. 4. The sequence of the diagnostic and analytical process
Source: prepared by the author based on (Stuss 2015)

Rys. 4. Sekwencja procesu analitycznego

3. Discussion of the research results

Smart governance in cities and municipalities is the implementation of projects that are based on available tools, often IT tools, and also proven governance projects. This means moving and using such tools that make it faster and better to diagnose certain things and reach them.

3.1. Residents' opinions of the city's/municipality's innovation and friendliness

In the surveyed municipalities, the highest expectations among residents relate to access to recreational areas (52%), efficient public transportation (48%), access to bicycle paths (45%), contact with science (40%), possibility to improve qualifications (34%) and access to electro-

nic communication (32%). The study indicates that the interviewed residents prefer access to innovative infrastructure, science, and recreation, and these factors determine the perception of the city as an innovative city. The results of the study in the area of residents' opinions will be discussed more broadly in detailed publications of the conducted research projects.

3.2. Opinions of municipality and city employees of the city's/municipality's innovation and friendliness

When examining the smart-city projects emerging in the entities, it was indicated that in the surveyed municipalities, 100% of the smart city projects include social and technological housing innovations and innovative solutions to support public participation, the projects implemented at the lowest level are projects in the field of urban audit, effective and innovative use of data about the city and its residents and users, the Internet of things and smart grids (71.4%).

The first dimension of the analysis of development policies was to assess their provisions in terms of the presence of direct references to the smart-city concept. The study examined the content of strategic documents with a distinction of provisions relating to the diagnosis and separately to the fragments that define the desired future states usually formulated in the form of visions, objectives, directions or development projects. It should also be mentioned that despite the fact that the whole study covered six cities of the Upper Silesian – Zagłębie Municipality, one of them (Wojkowice) did not have an up-to-date development strategy available.

In Gliwice, there are no express provisions concerning the smart-city concept, but an there is an objective to increase the use of information and communication technologies across the full social cross section of residents, including readiness to implement further projects in smart transportation, monitoring, and mobile applications related to specific public services.

In Dąbrowa Górnicza, there are no express provisions concerning the smart-city concept and in terms of vision and objectives, currently underway is the stage of formulation of the vision and the mission of embedding the city's strategy in the concept of smart specialization, i.e. indicating the most important directions of the city's development – the key element of the stage of preparation of an update of the strategy.

In Siemianowice Śląskie, in terms of the smart-city concept, the internal process is underway – implementation of solutions creating a smart city through both the use of modern technologies and the involvement of residents in decision-making processes, a distinctive characteristic – high awareness and implementation of smart-city solutions in city governance, among others on the basis of a project creating an integrated, partnership-based city information system to support local social and economic development. The vision, mission, and goals are defined as follows: vision – specialization of the city – competences, activities, conditions, and relations built by the city for the implementation of human smart-city solutions; goal – smart solutions supporting business and administration.

The above contents in relation to the diagnostic part of the analyzed documents only in two cases directly indicated the smart-city concept; in the case of Siemianowice Śląskie, it was additionally unambiguously positively understood as the internal processes and characteristics of the city. However, the provisions of the strategy of Mikołów also indicate a reference to the smart -city concept, but firstly, these are factors of tertiary importance in the document and additionally they were indicated either as weaknesses of the city or as external factors – opportunities. However, in the case of the remaining cities, the analyzed documents did not contain direct diagnostic references to the smart-city concept. However, the analysis of strategic provisions of the cities referring to the smart-city concept in terms of the future looks different through the vision, objectives, directions, or development projects, e.g. in terms climate protection or energy efficiency (Drożdż et al. 2021). All of the analyzed strategic documents contain these references, mostly as a part of the vision or the goals, but in the case of Dąbrowa Górnicza, these provisions refer only to smart specializations and not directly to the smart-city concept, which are defined unambiguously (Al-Gasawneh et al. 2021; Hussain et al. 2021).

The second stream of research is the analysis of local policies related to provisions that characterize the 4T capitals also presented in two contexts: diagnostic provisions and the contents that shape the desired future of the city. This enables the creation of a synthetic image that takes into account both the diagnostic parts and the components that shape the planned future of the city (usually included in the vision, objectives, directions, and undertakings/implementation projects). The indicator in question is shown in Table 1.

Table 1. The level of implementation of capitals – an attempt to directly refer to 4T capitals in the development strategies of selected cities of the Upper Silesia – Zagłębie Metropolis

Tabela 1. Poziom realizacji kapitałów – próba bezpośredniego odniesienia się do kapitałów 4T w strategiach rozwoju wybranych miast Górnośląsko-Zagłębiowskiej Metropolii

City	4T capitals			
	Talent	Tolerance	Technology	Trust
Mikołów	3	2	3	3
Siemianowice Śląskie	2	1	3	1
Dąbrowa Górnicza	2	1	2	1
Gliwice	1	1	3	1

Prepared by the author.

In order to improve the clarity of the analyses, the following rating scale using three levels was applied in the above list, where level 1 refers to a low level of inclusion of the aspects of 4T capitals in the strategy of the specific city. Number 2 indicates a medium level and 3 indicates a high level. This is shown graphically in Figure 5.

The conclusions for the above compilation can be considered according to both subjective and objective approaches. Taking into account the subjective approach, it is possible to present

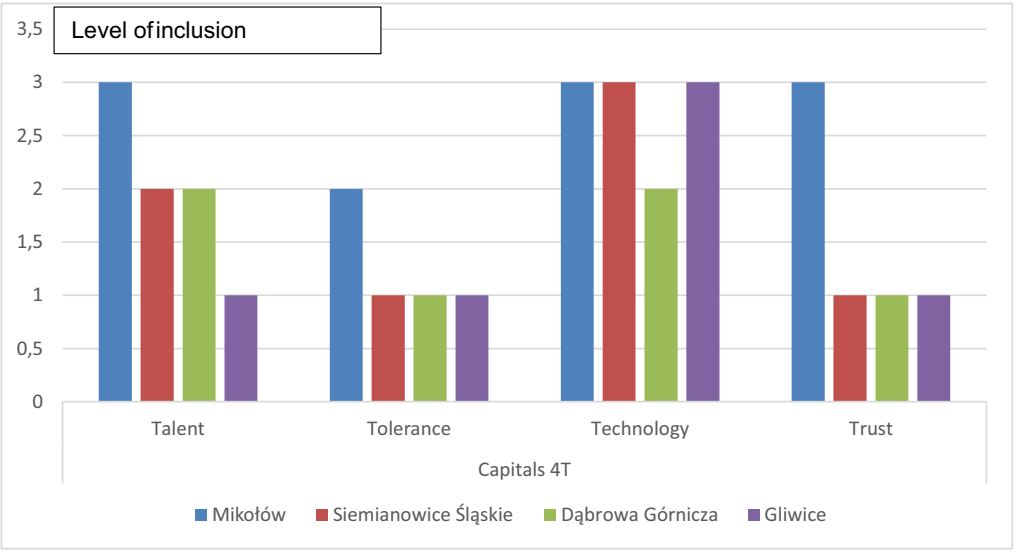

Fig. 5. The level of inclusion in the city's strategy of the values of the leading 4T capitals
Prepared by the authors based on the study

Rys. 5. Stopień uwzględnienia w strategii Miasta wartości wiodących Kapitałów 4T

a ranking of the analyzed cities in which Mikołów holds the first place, followed by Siemianowice Śląskie classified on the same level, Dąbrowa Górnicza in the next place, and Gliwice in the last place. The above assessment relates to the strategy document itself and as they were not prepared on the basis of uniform guidelines, differences in assessments are also related to the diversity of the procedure applied in the creation of the document itself and the adopted detailed methodology of work. Consequently, there are differences in the level of detail and the volume of the document itself, for example, the strategic document of Mikołów is very extensive and contains 238 pages, while the strategic documents of Siemianowice Śląskie and Gliwice are about fifty pages long and contain a synthetic diagnosis or conclusions from the diagnosis instead of detailed descriptions.

In the objective approach, it is also possible to rank the presence of 4T capitals in the strategy documents, which arrange the capitals as follows: technology, talent, trust, and tolerance. It can be clearly pointed out that by far the dominant dimension present in all strategic documents is technology. However, it should be noted that in the diagnostic dimension, its saturation varies and, in addition, the mere presence of a capital can be treated in two ways: as a stimulant and a destimulant. In almost all cases (except for the document from Gliwice) there is also a direct reference to "talent" in the strategic part; furthermore, in the case of Mikołów, this reference is also included in the diagnostic part. However, as for the direct presence of trust and tolerance, only in one case (Mikołów) was there a reference to this capital – in the case of trust, it was in every part of the document and in the case of tolerance, it was present only in the strategic part.

Practical manifestations of smart governance are eventually reflected in specific smart-city projects implemented in municipalities of the Upper Silesian and Zagłębie Metropolitan Area.

Research results of decarbonization area – sub-indicator: environment

Under the performed research, called "Smart City indicator analysis for the needs of implementing the smart-city concept and 4T potentials project – intelligent management of cities in the GZM", a sub-indicator has been created in order to describe the environmental aspect, constituting a component of a synthetic element, also taking into account social and economic aspects. This sub-indicator consists of the following parameters:

- the total emission of particulate pollutants per 1 km^2;
- the total emission of gaseous pollutants per km^2;
- pollutants trapped or neutralized in devices for reducing particulate pollutants (t/year);
- treatment stations with enhanced removal of nutrients;
- the share of parks, lawns, and district greenery in the surface area;
- the surface area of woody lands in the total surface area;
- selectively collected waste concerning overall waste;
- the number of planted trees/1000 inhabitants.

Values of the sub-indicator for specific municipalities in the GZM are presented in Figure 6.

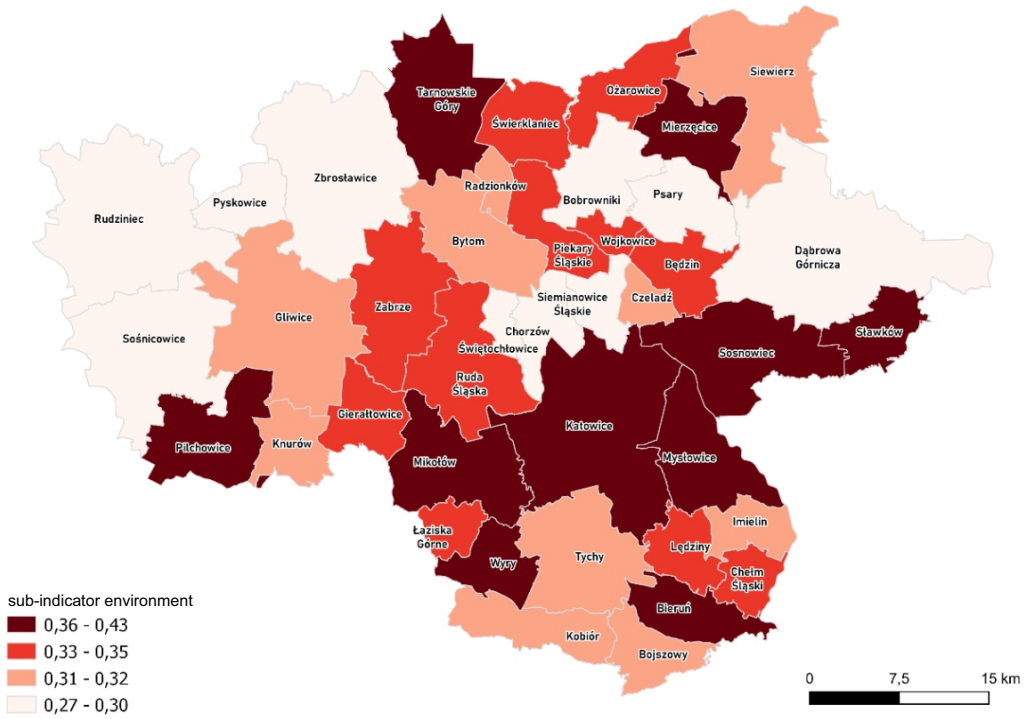

Fig. 6. Sub-indicator: environment
Source: the authors' own research for the smart-city project

Rys. 6. Subwskaźnik: środowisko

The completed surveys have shown that the inhabitants of the GZM have varying opinions about the condition of air in the municipalities in which they live. Half of them believe the air to be definitely or rather clean; the other half believe otherwise, as presented in Figure 7.

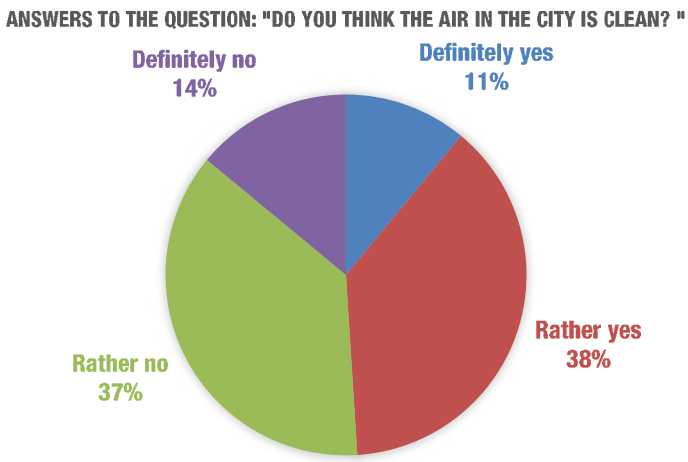

Fig. 7. Rating of air purity declared by the inhabitants of the GZM
Source: the authors' own research for the smart-city project

Rys. 7. Ocena czystości powietrza deklarowana przez mieszkańców GZM

Data from the regional system of air monitoring (GIOŚ 2020) confirms this. The highest average annual SO_2 concentration was found in the most industrialized Upper Silesia Metropolis in the initial survey years in the period from 2003 to 2006. The lowest concentrations were found in the Poznań Metropolis and, in recent years, in the Warsaw Metropolis as well. The results are also shown in Figure 8 below.

The period from 2003 to 2020 was also selected for NOx measurements and annual averages were prepared. Figure 9 (below) shows the results, with the largest decreases found for the Poznań Metropolis. In contrast, increases in annual averages were found for the Warsaw Metropolis in the period from 2012 to 2013. This resulted from the exclusion of natural areas associated with a national park from the survey.

In order to illustrate the PM10 particulate matter levels, data on the period from 2003 to 2020 were prepared as annual averages from the stations included in the surveys. Figure 10 shows the air measurements in the averaged form.

Emissions reduction is a significant challenge for many cities of GZM. It is prudent to allocate resources where the improvement can be of the largest scale and the fastest. Network management of the city can be useful in achieving this goal.

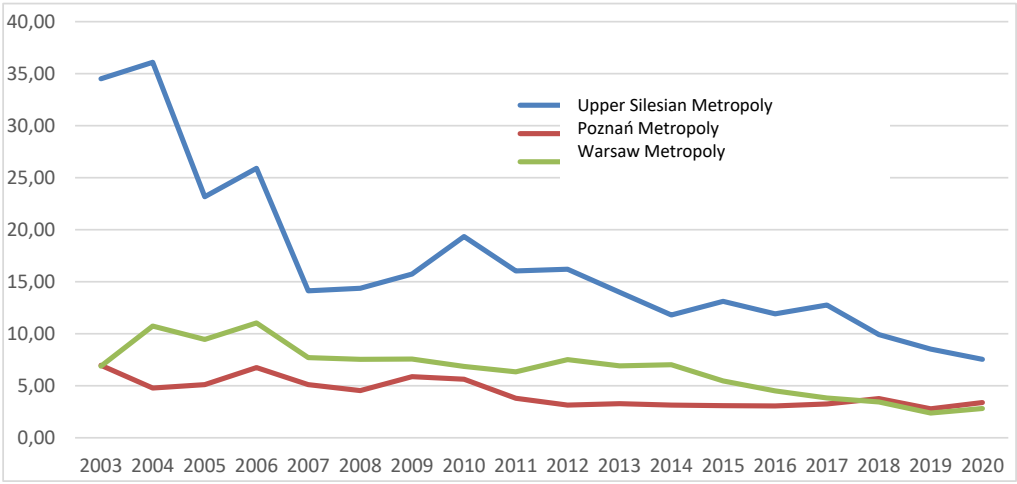

Fig. 8. The results of SO_2 measurements in three metropolises in Poland in the period from 2003 to 2020
Source: own elaboration based on measurements (GIOŚ 2020)

Rys. 8. Wyniki pomiarów SO_2 w trzech metropoliach w Polsce w latach 2003–2020

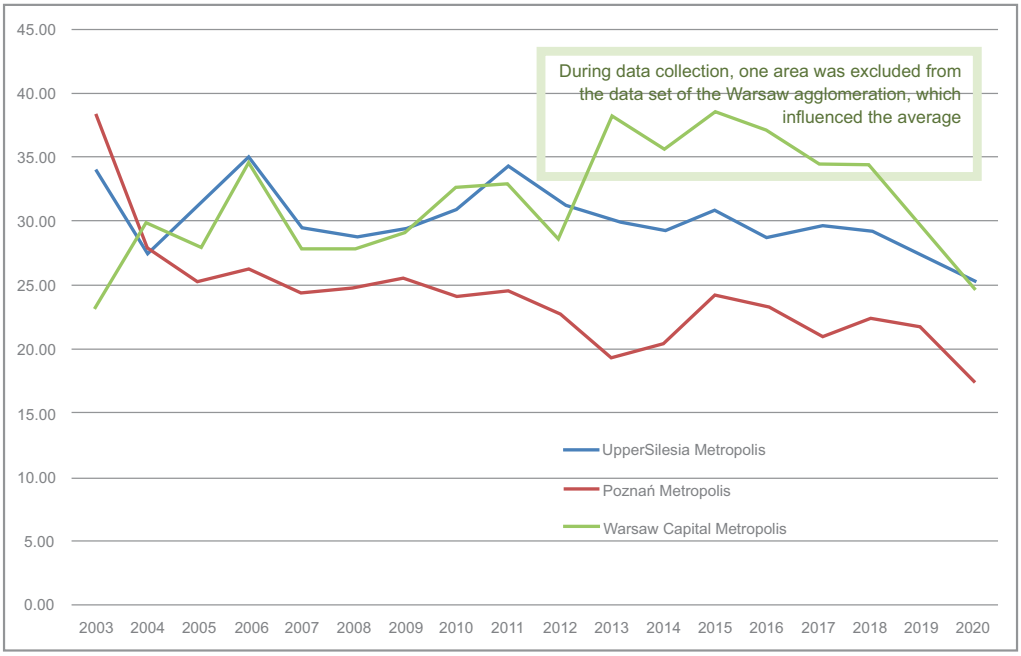

Fig. 9. The results of NO_x measurements in three metropolises in Poland in the period from 2003 to 2020
Source: own elaboration based on measurements (GIOŚ 2020)

Rys. 9. Wyniki pomiarów NO_x w trzech metropoliach w Polsce w latach 2003–2020

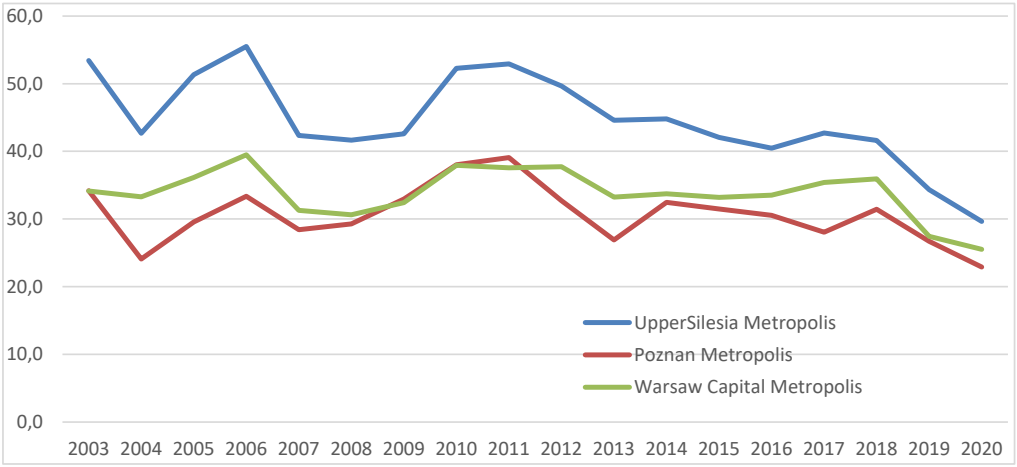

Fig. 10. The results of PM10 measurements in three metropolises in Poland in the period from 2003 to 2020
Source: own elaboration based on measurements (GIOŚ 2020)

Rys. 10. Wyniki pomiarów PM10 w trzech metropoliach w Polsce w latach 2003–2020

Conclusions

One of the smart-city building models is a development model based on innovative technical and economic infrastructure, learning organizations, and a strong university. This model could works well in metropolitan areas with large populations and high GDP and GDP per capita levels, ones that are home to large corporations, and ones where business centers and public sector institutions are located. To achieve the goal, smart cities are organizations for the creation of sectors of the innovative economy, which improve the quality of life of the residents, with an efficient governance center. The main approaches to a practical definition of the smart-city complex can be outlined as follows:

1. Actions carried out for the benefit of the residents should result in their high level of comfort, satisfaction, and pleasure derived from the functions performed in the municipality and the public services provided, raising the quality of life and the convenience, ease, and trouble-free functioning; in a broader sense, this approach should apply not only to the residents themselves but also to other users, namely the municipality's stakeholders.
2. Development based on professional, qualified staff who think in a modern way and is willing to develop allows the maximum use of the professional knowledge of the employees and provides them with available work tools and work flexibility; in a broader sense, it is a municipality that makes full use of its resources and capabilities, both human and economic.

3. A municipality that is not only smart but has smart procedures in place and implements them and is willing to use smart solutions in selected areas of its operation, e.g. in transport and mobility.
4. Caring for the environment, decarbonization processes. Implementation of wise solutions understood as innovative solutions or best solutions in combination with information exchange to search for these solutions.
5. Efficient use of technology, including the use of appropriate IT tools to manage projects for the benefit of the residents and those who implement these projects. It is important that a given project is supported by an appropriate IT tool.
6. Multidimensional, sustainable development referring on the one hand to individual functional areas and the interpenetrating socio-economic and environmental-spatial dimensions, and on the other hand, indicating the sustainability of the governance process itself, also leading to smart governance.

For a city to be called a smart city, it must be an urban center on the high technological level, this is the base. The basic features such a city should meet are: technology (innovation), talent, tolerance and trust.

A smart city requires a concentration of social and economic factors that are key to the sustainable improvement of the competitiveness of a smart city characterized by an innovative governance culture and a sustained absorption of that culture by its residents.

It is also important to point out possible areas of research development on this topic to deepen the initial recognition of smart-city concepts and 4T capitals. On the one hand, it is possible to extend the subjective participation of the surveyed municipalities beyond the pilot study carried out in selected cities of the Upper Silesian – Zagłębie Metropolis to all member municipalities, or to include other local government units from outside the metropolis in the study. On the other hand, it is possible to expand the scope of the research in question. This may include separating the implementation and monitoring part in the analysis of strategic documents. Additionally, due to the fact that the analyzed documents do not always contain express references to the smart city and 4T capitals concepts, or at least the fact that clear distinctions are not made between these concepts, it is possible to conduct an analysis focusing on the 4T capitals understood more indirectly through the factors/provisions that specify and develop them.

In connection with the above approach, it should be noted that the development of research is possible in terms of both a more detailed analysis of strategic documents and the referenced revitalization programs and programs of cooperation with NGOs. This is especially so because the last two document types analyzed for direct references to the 4T capitals did not indicate their presence in any case.

The study's findings provide important implications for organizations in the public sector, for policymakers, HR professionals, and organizational leaders. Public-sector organizations may face increasing difficulty in the future in attracting, developing, engaging, and retaining competent employees without a practical talent-management strategy. This in turn may limit the ability of these organizations to compete for talent with the private sector, which often manages talent well. As the study demonstrated, HR managers, including those in cities, face the challenge of

talent identification (Stuss 2015). Talent identification should be prioritized and actively supported by the senior management of organizations.

Technology is the most strongly emphasized in the objectives and directions of development of the analyzed cities in the Upper Silesian - Zagłębie Metropolis. There is a little less emphasis on the development of human capital, i.e. the sphere of talent, while an area of significant deficit is the issues of trust and tolerance. In the surveyed municipalities, no relationship can be observed between the level of inclusion of 4T aspects and the size, nature, and potential of specific cities. There is no operationalization of the objectives and directions specified in the strategy that indicate the implementation of the smart-city concept in operational and sectoral documents of the cities.

Recommendations

It is not possible to meet carbon reduction targets with a single technology or by applying them in a single area. What is needed is a multi-faceted, cross-technology approach that affects all areas of urban life, including: energy production, transfer, and use; construction; spatial planning; mobility. To effectively manage such a complex system, it is necessary to apply (implement or develop) smart-city solutions and at the same time adapt management tools in local administration units.

The level of emission reductions in the transportation/mobility area depends on the mix of tools selected. The most effective solutions – active mobility, public transport, and modern forms of shared mobility – require a profound shift in citizen awareness and collaboration among mobility ecosystem participants to develop an attractive value proposition that is an alternative to private car use. A necessary step, therefore, is to understand the structure and relationships among the participants of mobility networks.

The concept of a "smart home", defined as an object that effectively manages resources, services and their interrelationships in an integrated manner to meet the changing needs of its users while minimizing costs and continuously respecting the environment, can be scaled from the micro level (a single room or apartment) to the macro level (a city or a metropolitan area). This fractal approach to the problem makes it possible to identify potential savings in terms of capital expenditures, operating costs, and efficiency improvements as a result of simplified organizational processes.

Although local governments have considerable autonomy in shaping their transport policy and use it to develop strategic documents such as SUMPs, these documents are often not implemented and/or organizational and investment decisions are made in contradiction to the assumptions of strategic documents. The authors see the cause of this state of affairs in the increasing complexity of the urban mobility ecosystem and the silos nature of organizational structures and recommend, the introduction of network management tools and the revision of

organizational architecture in such a way that raises the level of the creative capital of local government employees.

Sustainable development also involves the development of social capital and intersectoral cooperation defined as multidimensional support for activities aimed at enhancing and sometimes restoring the quality of the natural environmental. In this case, communication and information sharing are important. The development of cross-sectoral cooperation can be carried out using tools such as urban labs, multifunctional dialogue platforms, and formal and informal meetings leading to the creation of partnership-based projects.

It is necessary to intensify revitalization processes and priority investment processes understood as, among other processes, the intensification and acceleration of revitalization processes both in the infrastructural dimension and in the functional-spatial dimension, but especially in the social dimension. In this area, it is necessary to be open to investment processes involving sustainable urban mobility, linear infrastructure, and linear parks.

For large-scale investment projects to take place, open data must be developed to facilitate decision-making and minimize risk, particularly including increased computerization and the automation of data collection and sharing, including open data, resulting in increased usability and availability of data and reduced risk in the decision-making processes for actors from all sectors. It may also be necessary to expand the set of reliable data enabling the decision-making process and supporting the participation of local entities in creating the innovative future of cities.

Low carbon as a policy will be more widely known and understood when systemic smart-city education and metropolitan branding are launched regarding the building and strengthening of a coherent metropolitan brand both externally in the national and international arena and internally within the metropolis. Such systemic smart-city education needs to be developed as one that targets local government officials in particular, as well as children, young persons, and seniors in combination with an increase in the importance of the educational potential, including the academic potential of the metropolis.

Improving air quality, especially during the heating season, is possible to a large extent by reducing low emissions. A network approach to district heating-system management reduces overall emissions and also increases the attractiveness of district heating relative to much more carbon-intensive alternatives by improving technological and cost efficiency through smart-city solutions. Due to its unique position, the Upper Silesian – Zagłębie Metropolis may assume the role of an orchestrator and lead to partial or full technological integration of district heating systems operating in its territory, thus providing added value for residents and heating companies.

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Grzegorz KINELSKI

Trendy *smart city* w otoczeniu zrównoważonego rozwoju jako wsparcie procesów dekarbonizacji

Streszczenie

Koncepcja *smart city* może odnosić się do miast, które wykorzystują technologie informacyjno-komunikacyjne w celu zwiększenia interaktywności i efektywności infrastruktury miejskiej i jej elementów, a także podniesienia świadomości mieszkańców, m.in. tak ważnych społecznie kwestii, jak efektywność energetyczna i dekarbonizacja. Aktualne priorytety i cele strategiczne miast i obszarów metropolitalnych obejmują ochronę klimatu, redukcję zanieczyszczeń powodowanych użytkowaniem środków transportu oraz źródeł ciepła lub energii. Rozwój technologii i ewoluująca koncepcja *smart city* wpisują się w bardziej efektywne wykorzystanie zasobów, globalne trendy demograficzne oraz zachodzące procesy urbanizacyjne. Wynika to z ewoluującego potencjału miast, który uruchomiły nowe technologie informacyjne i komunikacyjne (ICT). Zmiana sposobu funkcjonowania miast wpisuje się w koncepcję zrównoważonego rozwoju, która zakłada przemyślane wykorzystanie zasobów w taki sposób, aby były one wystarczające dla zapewnienia dobrobytu obecnej generacji, ale także dla zaspokojenia potrzeb przyszłych pokoleń. Szczególnie jest to ważne w zasadzie zrównoważonego rozwoju, która zakłada jak największą synergię między ludźmi a otaczającym ich światem. Dlatego istotą idei zrównoważonego rozwoju jest dążenie do dobrobytu społeczeństwa przy zachowaniu integralności ekosystemu. Badania przeprowadzone wśród mieszkańców miast pokazują, że zgodnie z ich rozumieniem koncepcji *smart city*, element technologiczny jest tak samo ważny jak to, że miasto jest przyjazne mieszkańcom, mądrze zarządzane i dobrze zorganizowane, a potrzebne zasoby są zawsze w we właściwym miejscu i we właściwym czasie. Celem niniejszego opracowania jest analiza potencjału innowacyjnego wybranych miast dużej metropolii pod kątem koncepcji *smart city* oraz kapitałów 4T. Tematyka związana jest z poszukiwaniem przez władze miast nowych modeli i narzędzi kształtowania zrównoważonego rozwoju w celu poprawy dostępu ich mieszkańców do usług i udogodnień komunalnych, a także zwiększenia ich wpływu na przyszłość ich miast w tak trudnych, trwających procesach jak dekarbonizacja. Głównym celem badania było zidentyfikowanie, w jaki sposób władze wybranych miast włączają tematykę *smart city* do lokalnych polityk dla osiągnięcia celów dekarbonizacji. Badania oparto na ankietach mieszkańców i pracowników komunalnych oraz analizie dokumentów lokalnych i danych środowiskowych o zanieczyszczeniach.

SŁOWA KLUCZOWE: zarządzanie miejskie, inteligentne miasto, zrównoważony rozwój, dekarbonizacja, potencjały 4T