Smart cities as a tool for environmental sustainability: opportunities and challenges

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Abstract. **The article's research focus is to investigate the impact of technologies used in smart cities to achieve environmental sustainability. The research methods used to review scientific studies worldwide on the problem under consideration, analysis and synthesis, comparative analysis, and logical approach. The information and communication technologies in smart cities aim to promote sustainability and provide adequate services to citizens, thereby improving their quality of life. Specific characteristics of smart cities are the extensive use of technology, real-time monitoring, innovation, and citizen empowerment, with a constant focus on sustainability. Analysis of the cited examples shows that technologies are being deployed in smart cities to improve transportation systems, deal with traffic jams and waiting times at traffic lights, and more with real-time data analysis. In most examples, information and communication technologies create a smart grid to achieve optimal energy use and improve the efficiency, reliability, and economy of the provided utility services. Self-monitoring and control of smart grids are realized using intelligent sensors and smart meters for energy transmission and distribution for real-time analysis of current consumption. An intelligent energy system involves using technologies for efficient energy production and distribution. The conducted case study on the effectiveness of the smart city in terms of environmental sustainability establishes that the sustainable management of resources and reducing the harmful impact on climate change and the environment requires optimizing the use of energy and resources and increasing the use of renewable energy sources. Analysis shows how technology can achieve environmental sustainability by reducing carbon emissions from cities, improving air quality, and optimizing the use of natural resources. Implementing intelligent systems and applications can reduce greenhouse gas emissions by an average of 20%, water consumption by up to 30%, and the amount of non-recyclable solid waste by around 15-20%, depending on the city's specific characteristics.**

Keywords: environment, efficiency, smart, technology.

I. INTRODUCTION

In recent years, climate change has acquired the significance of a global emergency and affects human well-being and the sustainability of other forms of life. Climate change is a significant threat to human health, affecting the physical environment and all aspects of both natural and human systems – including social and economic conditions and the functioning of health systems. The world's population lives in cities, consuming many natural resources, including energy, raw materials, fuels, and water. The environmental sustainability of cities is increasingly challenged by air pollution, traffic and waste management issues, ageing infrastructure, and over-urbanisation. One of the possible solutions for achieving environmental sustainability is the smart city. The smart city concept is related to a sustainable city based on the use of innovation and information and communication technologies to reduce pollution, provide better services to citizens, and use natural resources wisely. The article presents smart cities' main characteristics and possibilities for achieving environmental sustainability. The article provides up-to-date and detailed information related to environmental sustainability issues and smart cities' role in reducing greenhouse gas emissions, integrating technology into urban infrastructure, resource management, and possible technological limitations and challenges.

II. MATERIALS AND METHODS

The material includes a review of scientific research worldwide on the problem at hand to identify the opportunities and challenges of using smart cities for environmental sustainability. The following scientific methods were used in the research process - analysis and synthesis, comparative analysis, and logical approach.

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III. RESULT AND DISCUSSION

A. Key features of smart cities – evolution of the concept, technological innovation, examples of successful smart city projects

There are many definitions deriving the concept of the smart city. The key features of a smart city are computer technology to manage critical infrastructures and components, achieve intelligent transportation, intelligent traffic and waste management, intelligent health system and education, and more efficient and fair living conditions [22]. Information and communication technologies are fundamental in making cities smart, providing real-time data, and making intelligent decisions. Integrating information and communication technologies offers the opportunity to improve the management and use of available resources and infrastructure in cities, simultaneously improving the quality of life [7]. Although interest in smart cities has increased in recent years, historically, the concept was born in the 1980s during a discussion of ideas about the possibilities of changing the management of cities and making them more flexible for adapting to global markets. The concept of a smart city began to be used in the 1990s to introduce a new urban planning policy. After 2000, high-tech companies such as Siemens and IBM began to use the term to describe the possibilities of integrating information and communication systems in urban infrastructure [4]. The development of the concept of smart cities is also associated with the use of interchangeable terms, such as "intelligent city" and "digital city". Most definitions associate the smart city with intelligence, improved quality of life and efficiency. Information and communication technologies in smart cities aim to promote sustainability and provide adequate services to citizens, thereby improving their quality of life. Specific characteristics of smart cities are the extensive use of technology, real-time monitoring, innovation, and citizen empowerment, with a constant focus on sustainability [19]. Computers, computer networks, smartphones, television, and the Internet are essential components of the smart city architecture to ensure the connectivity of the services provided with the infrastructure. Distinctive features of smart cities are [9]:

- Positive attitude towards business – a sense of cooperation is created between the local government and companies to promote the development of their activities.
- Openness – regarding the introduction of innovations that benefit citizens.
- Real-time monitoring and control – city authorities effectively use surveillance cameras to regulate traffic, reduce crime, and more.
- Improving the well-being of citizens – by using various technologies, such as biometric identification, GPS, data mining software, etc., as well as developing solutions for emerging problems in the management of cities.
- Sustainability (social and environmental) to reduce greenhouse gas emissions through technologies.

The latest technological advances in smart cities are the Internet of Things (IoT), big data, machine learning, fifth generation (5G) networks, various robotic and automated systems, electric vehicles, etc. [1]. The smart city's infrastructure consists of the road network, traffic management systems, traffic lights, water supply, power supply, fire safety, hospital system, residential and public buildings, etc. Technology transforms the physical infrastructure of cities into a smart one that is more efficient, secure, and safe. Smart city infrastructure includes software, sensors, firmware, and more that provide information about carbon footprint and sustainability [10]. An example of a smart city grid can be given with the power transmission system, which consists of various conventional and renewable energy sources. These meters allow load balancing and quick elimination of errors that occur, reliable energy delivery to consumers, and real-time reporting of consumption. Smart buildings, which use various sensors, hardware and software, smart meters, access control, video surveillance, and power and lighting management, are part of the infrastructure. In recent years, smart cities have started to include more and more "green" buildings, where optimal energy efficiency and environmental control are achieved to reduce the carbon footprint. IoT enables processing of large databases, thereby achieving maximum energy and operational efficiency of the building, more optimal use of resources and reduced operating costs [22]. The three key characteristics of smart cities are intelligence, connectivity, and technology (tools). IoT enables the use and connection of smartphones, sensors, smart meters, networks, software and firmware, buildings, vehicles, and energy systems. With the help of IoT, the implementation of communication between all specified devices and structures, exchange of information and data and achievement of connectivity are achieved. Smart cities use various sensors in transportation, buildings, networks, and communication services, performing different tasks such as location determination, recognition, monitoring, pollution control, etc. [5]. On the other hand, big data is inherently about large data sets that are complex and difficult to manage using traditional tools. In smart cities, big data is generated from sensors, smart devices, media, medical information, transactions, institutional archives, and others, which creates challenges for their management, sharing, search and storage [12].

Examples of successful smart city projects are presented in Table 1.

TABLE 1 SUCCESSFUL SMART CITY PROJECTS [3; 13]

City	Smart city projects
London	The London Development Database enables citizen access to building permit management and real-time stage tracking implemented for smart meters for energy and water use. Heathrow Pods is a unique form of transport using driverless, intelligent vehicles to transport passengers from the airport to the city.
New York	A LinkNYC network has been implemented to replace phone booths with free Wi-Fi hotspots that are widely distributed throughout cities. Midtown in Motion technology has been implemented to manage traffic and reduce congestion during peak hours, using speed sensors and a data centre. The water supply has an intelligent system allowing real-time monitoring of readings and online bill payment.

City	Smart city projects
Tokyo	Systems have been installed to control and coordinate the various renewable energy sources and use intelligent metering devices.
Copenhagen	A system has been implemented to control air quality, waste management and energy consumption to reduce emissions. In one of the districts (Nordhavn) a test system (EnergyLab) is used to achieve sustainable transport, electricity, and heating.
Amsterdam	An automated system has been built for sharing bicycles, paying for parking by phone and intelligent waste collection by paying a fee only for garbage thrown away.
Singapore	The city is one of the most technological. The innovations introduced include the first innovative hospital that uses Big Data in the provision of health services, the use of unmanned taxis, as well as the Digital Twin application, which is a virtual model of the city, allowing citizens and tourists to easily navigate and discover sites and services, with using real-time information.
Dubai	The city uses artificial intelligence in digitizing services provided to citizens and city lighting, transport, and communication systems.

Analysis of the cited examples shows that technologies are being deployed in smart cities to improve transportation systems, deal with traffic jams and waiting times at traffic lights, and more with real-time data analysis. In most of the examples mentioned, information and communication technologies are used to create a smart grid to achieve more optimal use of energy and improve the efficiency, reliability, and economy of the provided utility services. Self-monitoring and control of smart grids are realized using intelligent sensors and smart meters for energy transmission and distribution for real-time analysis of current consumption [6]. Although information and communication technologies are at the heart of smart cities, cooperation with local government and citizens is crucial in achieving environmental sustainability and economic development [19].

B. Environmental sustainability in smart cities

The positive impacts of making cities smart are numerous. In terms of environmental sustainability, the positive effects are related to more efficient use of energy, reduction of CO2 emissions, creation of energy-efficient buildings (green buildings) and a change in the behaviour of end-users of utility services [21]. An intelligent energy system involves using technologies for efficient energy production and distribution. An essential part of the intelligent energy system is using green energy, photovoltaic energy, wind energy, etc. Achieving efficiency from the intelligent energy system is possible through smart infrastructure, grid, and meters. Information and communication technologies are at the core of the intelligent energy system that collects consumer information and data and shares it with energy providers. Technologies also control energy consumption for ventilation, air conditioning and heating. Critical factors for efficient use of energy are innovative management and intelligent management, achieving low energy loss, safety and security of the system, and integration of different types of energy – from biofuels to wind and solar panels. Smart meters measure energy usage and report data in real-time, facilitating payment reliability and limiting opportunities for human error [18].

The applications used in smart cities must deal with several challenges related to environmental degradation and climate change. Examples of such applications are technologies for precision agriculture, waste management, use of sensors to manage energy use, etc. Smart (precision) agriculture uses drones and sensors based on artificial intelligence to optimize the use of fertilizers and pesticides. Smart waste management is about using sensors to observe and monitor the disposal of waste to reduce the harmful impact on the environment [8]. The conducted analysis found that sensors, mobile applications, and warning systems are needed to achieve a sustainable and green environment in smart cities. The intelligent sensors that are integrated into the waste collection bins allow for 24-hour monitoring and sending information about the current state of the garbage to the responsible institutions [20]. Public disclosure of information also encourages citizens to collect their garbage separately to take care of the environment. Using such intelligent sensors also reduces the fuel costs of the cleaning companies because the trash is collected as needed, reducing carbon emissions. Another advantage is that citizens receive real-time information on the best place to dispose of their junk to keep the environment clean. Using an intelligent waste management system solves the problems related to the separate collection and sorting of waste in most residential areas [18]. The main benefits of using an intelligent waste management system are related to [17]:

- Reducing the level of pollution - using a 24-hour monitoring system providing information from sensors allows optimal waste management with the lowest possible costs for the city budget.
- Increasing community engagement - in addition to reducing the level of pollution, the smart system encourages citizen engagement in achieving environmental sustainability.
- Using a free application by citizens encourages them to dispose of their garbage in the appropriate place and participate in cleaning the environment.
- Achieving a sustainable environment - during normal waste collection, trucks pass through residential neighborhoods along a predetermined route without information on whether it is essential, which, in addition to high economic costs, also leads to the release of a large amount of carbon monoxide. Innovative applications enable the reduction of unnecessary journeys, saving fuel costs and combustion and reducing the harmful impact on the environment.

To achieve ecological stability, it is necessary to implement strategies for planning and managing urban green spaces, including parks, gardens, and green spaces, to reduce noise and pollution and maintain ecosystems.

C. Opportunities and challenges

The possibilities for smart cities are many. First, increasing the effectiveness of the policies implemented by local authorities and improving services for citizens

(such as electronic services) increase the possibilities of responding to emergencies, improving security, reducing crime, etc. In this regard, smart cities' focus is improving citizens' quality of life, including mobility, healthcare, and access to services. Secondly, smart cities promote economic development by investing financial resources and implementing innovations in various sectors of the economy. Thirdly, smart cities improve environmental protection by reducing pollution, increasing renewable energy sources, and achieving sustainable water supply. To achieve environmental sustainability, smart cities invest resources to implement smart infrastructure, including that of a sewage system [19]. Smart infrastructure comprises multiple devices enabling connectivity, real-time data collection and analysis. The benefits of so-called green infrastructure are numerous, including addressing environmental challenges such as pollution, flooding, carbon emissions, etc. Most cities that want to be smart focus on activities related to solving energy problems and achieving environmental sustainability to improve the quality of life of their citizens. Smart cities are using technologies to address the many challenges of natural resource management. One of the significant challenges is related to the dependence on data and information, as well as their management and analysis, which gives rise to the need for substantial investments in infrastructure and technology. Another challenge is the efficient allocation of resources to achieve long-term sustainable development goals. The management of renewable energy systems and other natural resources requires, on the one hand, significant financial resources to be invested and, on the other hand, the implementation of effective communication strategies to achieve citizen engagement. Dealing with the mentioned challenges requires coordinating the actions of the local authority and all interested parties [2].

Despite the undeniable advantages, smart cities face various challenges. First, the technological dependence of towns should be pointed out, which leads to an increase in the need for financial investments and various materials for building infrastructure and electricity. Suppose even just one part of the necessary materials (e.g. semiconductors) is delayed. In that case, it disrupts the supply chain and the inability of smart cities to provide energy to their citizens. Secondly, the volume of collected data and information increases the risk to personal data privacy due to the use of multiple intelligent sensors. Similarly, constant connectivity requires companies to significantly increase their spending on maintaining the security of their information systems and on cybersecurity to protect their sensitive data and information. Thirdly, the difficulty of achieving connectivity in cities with millions of people of all ages, some of whom may refuse to use modern technology daily, should be pointed out [16].

D. Case study Analysis

In environmental sustainability, key indicators to measure the results achieved by smart cities are reduced greenhouse gas emissions, reduction of non-recycled waste, and more efficient use of water resources. New York is one of the cities with actual initiatives to achieve sustainability, including through legislative change to reduce harmful emissions. The use of modern technologies is essential to achieve economic growth in the city, as well as to attract investment and provide multiple services to make the local economy competitive. One of the city's first areas of improvement is energy use. In 2013, the local government introduced an efficiency program that retrofitted lighting with LED technology, helping reduce greenhouse gas emissions by 900 metric tons and saving over $800,000 annually. The city's priority is reducing water consumption and wastewater generation. For this purpose, an intelligent system for automatically reading water meters has been introduced to the town, which warns users in real time about water leaks and provides information on opportunities to reduce consumption. On an annual basis, the intelligent system is estimated to have reduced water consumption by over 1 billion gallons, saving citizens over $74 million. In terms of waste, smart trash and recycling bins have been introduced throughout the city. The bins are powered by solar energy and equipped with a chip that shows when the container is full and prompts cleaning companies to process it. After the implementation of the system, the efficiency of garbage collection in the city has improved by up to 80%, and due to the reduced time for the trucks to move, greenhouse gas emissions have also decreased. New York is a city that is constantly investing in technology to become innovative. After 2020, a program will begin to install intelligent technologies and sensors in individual neighborhoods of the city, aimed at improving the services provided, including traffic management, water leak detection, street lighting and air quality monitoring [14].

Singapore is another example of an intelligent city that has achieved high environmental sustainability. The city has invested a lot of resources in using electric vehicles and implementing innovations in transport. Emissions in the town are incredibly high, with greenhouse gases mainly from the increased use of air conditioners, which are a significant source of energy use given the specific tropical temperatures. Numerous parks, a centralized system for cooling and regulating the temperature in business buildings and citizens' homes, and numerous green areas have been built in the city to limit harmful emissions. The digitization of the city also includes many innovations for building smart homes, providing health services, education, etc. For more optimal energy use, Singapore is switching to using natural gas and covering the roofs of public buildings with solar panels to harness solar energy. Introducing intelligent LED lights in the city reduces power by 15% [11]. The town is gradually moving to the use of electric cars. These efforts minimise energy use by 8 million megawatt-hours per year, combined by households and businesses, reducing 3 million tons of greenhouse gases. The city's activities in the field of Environmental Sustainability are also aimed at achieving a circular economy by increasing recycling for a more efficient use of resources. One of the activities undertaken is the recycling of the used water, as well as the use of part of the incinerated waste in construction. In just one year, waste has been reduced by 30%, and water consumption has been reduced by 10% to 130 liters per capita, through the use of smart meters. Environmental sustainability is also achieved by banning the movement of cars in the central part of the city, freeing up spaces for green areas. In addition to the use of green energy and buildings, to promote Environmental Sustainability, initiatives are being implemented in the city to change the way of life and established values of citizens, such as

using more bicycles, awareness of opportunities to reduce the carbon footprint, etc. [15].

The Norwegian capital, Oslo, is one of the remarkable examples of resilience. The city is distinguished by its large green areas (47% of the territory) and low carbon emissions. Oslo uses 60% of its total energy consumption from renewable energy sources (mainly hydropower). The city centre is car-free, with many resources invested in environmental projects, including electric transport and bicycles. An interesting fact is that the city uses biogas as a source of energy for city transport and heavy-duty vehicles (such as waste trucks), which is produced locally. About 60% of all cars are electric, with ownership and use encouraged with tax cuts and plenty of charging stations. A regulatory restriction has been introduced for construction without the use of fossil fuels, as well as the use of machines with zero emissions [23]. In comparison, data on greenhouse gas emission reductions show that after transforming cities into smart cities, greenhouse gas emissions decreased by 900 metric tons/year in New York, 3,000 in Singapore, and 4,500 in Oslo (Fig. 1).

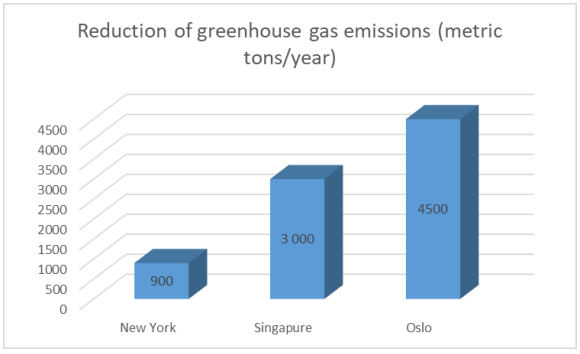

Fig. 1. Reduction of greenhouse gas emissions (metric tons/year)

Water use was also reduced, from 30 to 45% in the three analysed cities (Fig. 2).

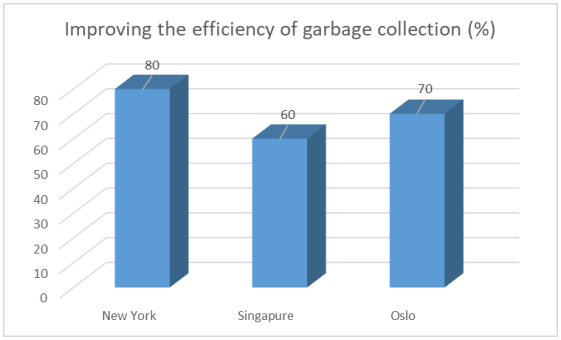

Fig. 2. Reduction of water consumption (%)

An improvement in waste management efficiency is reported - between 60 and 80%, with the most significant improvement in New York (Fig. 3)

The conducted research on the effectiveness of the smart city in terms of environmental sustainability establishes that the sustainable management of resources and reducing the harmful impact on climate change and the environment requires optimizing the use of energy and resources and increasing the use of renewable energy sources.

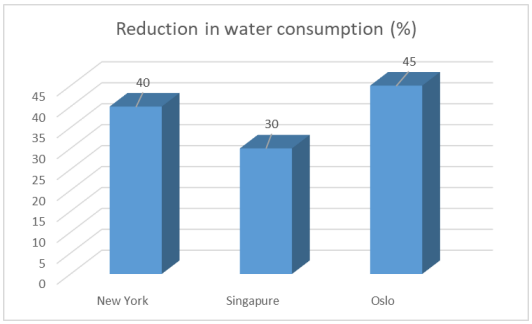

Fig. 3. Improving the efficiency of garbage collection (%)

I. CONCLUTION

Rapid urbanization leads to air and water pollution, deteriorating citizens' well-being and social inequality. Smart cities are defined as reliable solutions for the mentioned problems, in which, using information and communication technologies, urban sustainability can be achieved. The analysis shows how technology can lead to achieving environmental sustainability by reducing carbon emissions from cities, improving air quality, and optimising the use of natural resources. Implementing intelligent systems and applications can reduce greenhouse gas emissions by an average of 20%, water consumption by up to 30%, and the amount of non-recyclable solid waste by around 15-20%, depending on the city's specific characteristics. The future development of towns requires technology to be accepted as a mandatory part of the tools used to solve various environmental problems. A change in the behaviour of citizens is also recommended, which should be achieved by raising awareness.

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