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Integration of renewable energy systems in the infrastructure of smart cities

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Интеграция на възобновяеми енергийни системи в инфраструктурата на интелигентните градове

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Abstract: All initiatives related to the reduction of energy consumption, the use of renewable energy sources and the construction of smart cities are the main priorities of modern society. Profitability, ecological footprint, and reliability are factors that determine the investment choice. Globally, there is growing commitment to climate change mitigation, with the research community and businesses innovating in smart cities, green energy, and energy efficiency. The report examines the importance of renewable energy in making cities bright and the challenges and prospects for using renewable energy. Renewable energy sources, such as solar, wind, hydro and geothermal, have significant potential to generate clean, abundant energy without the harmful emissions associated with fossil fuels. It is crucial to understand the importance of renewable energy sources and the critical role that smart meters play in realizing their full potential.

Key words: *s*mart, renewable, energy, benefits, cities, risks, opportunities

Резюме: Всички инициативи, свързани с намаляването на потреблението на енергия, използването на възобновяеми енергийни източници и изграждането на интелигентни градове, са основните приоритети на съвременното общество. Рентабилността, екологичният отпечатък и надеждността са фактори, които определят инвестиционния избор. В световен мащаб има нарастващ ангажимент за смекчаване на изменението на климата, като изследователската общност и бизнесът правят иновации в интелигентните градове, зелената енергия и енергийната ефективност. Докладът разглежда значението на възобновяемата енергия за осветяване на градовете и предизвикателствата и перспективите за използване на възобновяема енергия. Възобновяемите енергийни източници, като слънчева, вятърна, водна и геотермална имат значителен потенциал за генериране на чиста, изобилна енергия без вредните емисии, свързани с изкопаемите горива. От решаващо значение е да се разбере значението на възобновяемите енергийни източници и критичната роля, която интелигентните измервателни уреди играят за реализиране на пълния им потенциал.

Ключови думи: умни, възобновяеми, енергия, ползи, градове, рискове, възможности.

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Introduction

The concept of intelligent cities dates to the 1960s and 1970s when the US Bureau of Community Analysis began using databases, aerial photography, and cluster analysis to collect data, target resources, and issue reports to target services, mitigate the effects of disasters and reduce poverty [The Welding Institute (TWI), 2023]. This resulted in the development of the initial wave of smart cities. More than half the world's population lives in cities, which is expected to grow to 66% by 2050, adding another 2.5 billion people to the urban population over the next three decades [DESA, 2018]. With this population growth comes the need to manage resources' environmental, social, and economic sustainability. Smart cities allow citizens and local governments to collaborate to launch initiatives and use innovative technologies to manage assets and resources in the growing urban environment. Renewable energy is an integral part of smart cities. Renewable energy sources (wind energy, solar energy, hydroelectric energy, ocean energy, geothermal energy, biomass, and biofuels) are alternatives to fossil fuels that help reduce greenhouse gas emissions, diversify energy supplies, and reduce dependence on unreliable and volatile fossil fuel markets, especially oil and gas.

The article aims to analyse the possibilities for integrating renewable energy systems into the infrastructure of smart cities. The scope of the paper explores the challenges and prospects of using solar, wind, biomass, and geothermal energy in smart cities to achieve sustainable development.

1. Basics of smart cities and renewable energy

In the last few years, the concepts of "smart or intelligent city" have increasingly entered our daily lives and work in the media and scientific circles. A smart city can be both the whole city and a particular territory, where electronic and technological infrastructure, such as information and communication technologies, are used to collect data and make real-time analyses to provide certain essential services to solve urban problems. With the growing need for sustainable cities in the global context of climate change, the concept of an intelligent city places the environment and surrounding climate, including the interaction between technology and nature, promoting the integration of climate strategies and citizen participation to adapt to climate impacts. The main goal of a smart city is to improve well-being and adapt to climate change by providing services that support every resident. Intelligent cities improve the city's daily activities, such as public transport and mobility, electricity and water supply, sewage systems, etc. Using this data, local governments can extract useful information and provide practical solutions to correct prevailing urban problems [Albino et al., 2015].

There are numerous examples and applications of intelligent technologies. These can be in the form of software decision-making, innovative technologies connected to other devices via the Internet, or applications that allow the user to control their devices quickly and conveniently and can be connected to an external service provider. Smart home technology has become very common in recent years. They cover various applications, such as security systems, lighting systems, intelligent cameras, remote controllers, sockets, and plugs. These technologies can provide remote access to the homeowner as well as allow the user to perform various home automation tasks such as turning off lights, applying door locks, monitoring the home, and more. Devices such as smart thermostats, for example, can show how much energy is being used when changing the temperature in our homes, resulting in much less energy being wasted. On the other hand, bright lighting can reduce electricity consumption by using dimming lights on streets without pedestrians or traffic. Such lighting systems are often also equipped with central management software that monitors usage and drives maintenance efficiency. An example of intelligent

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management could be a waste initiative [Ismagilova et al., 2019]. A city that implements innovative waste management solutions can reduce costs by emptying waste containers by using sensors installed in the containers. Sensors can monitor the individual waste level; thus, the containers are only emptied when full rather than on a standardized schedule. Therefore, traffic is also reduced since there are fewer specialized vehicles for waste on the streets, which contributes to the reduction of greenhouse gas emissions and improves the air and climatic conditions in the cities [Attaran et al., 2022].

An essential part of smart cities is renewable energy. The main types of renewable energy are wind, solar (photovoltaic), geothermal, hydro and biomass. Wind turbines use large fins (wind turbines) on the cylinder head and in the mop to catch the kinetic energy the wind creates. The heat of the heat pump is linked to the heat pump gene, which in turn conserves the heat's kinetic energy in electricity. Chain technologies use light or electricity. Magnetic radiation from the beam is stored in an electronic file. Photovoltaic (PV) loop cells contain a polysyndeton plate, positive on one side and negative on the other. When the light reaches the cell, the semiconductor absorbs the reflected light and energy in the form of electrons. The electric field captures these electrons in the form of electric current [Lara et al., 2016]. This system's difficulty in generating electricity depends on the polysyndeton material, together with the circularity of the surrounding circuit. Geothermal energy originates from the Earth's core, known as geothermal energy. Geothermal power plants usually use wells to pump the hot water from the geothermal cells and send it to the heat exchanger. Therefore, water and waste can be reused, making it a renewable energy source. Like wind turbines, hydroelectric plants use the kinetic energy of flowing water into electricity with the help of a turbine generator. The electricity output depends on the volume and the change in the head or head of the flowing water. Biomass - organic material such as wood, tyres, and other municipal waste - is usually wasted but is considered renewable. The burning of biomass produces papa under high pressure, the third type of gene for electricity production. Biomass is also found in liquid or gaseous fuels for transportation. The emissions from biomass, however, depend on the material used and are often higher than those from other clean sources [Hoang et al., 2021].

2. Strategies for the integration of renewable energy systems in smart cities

Due to the increasing demand for energy worldwide, many cities are looking to meet this challenge by using clean, safe, and reliable power from renewable sources, incl. solar, and providing sustainable public services. The implementation of various solar projects in urban infrastructure construction shows that they are practical and profitable. One of the most important benefits of implementing solar solutions in urban infrastructure is improving the ecological condition by reducing harmful emissions in the atmospheric air, ensuring the protection of human health, and using local sources of solar energy [Sravya et al., 2020]. In this magazine article, we will look at different applications of solar installations in urban infrastructure. The installation of photovoltaic panels on the roofs of buildings is one of the most common applications of solar installations in the urban environment. However, they can find many other uses for it. This includes using them to regulate road traffic through solar traffic lights, solar road signs, warning light signalling, solar lighting of streets, parks, gardens, and fountains, building solar roofs for parking lots and public garages, solar charging stations for electric cars and others. Most solar traffic lights use high-brightness light-emitting diodes (LEDs) because they are more reliable and have more advantages than other lighting devices. They are characterized by higher energy efficiency, a longer operating cycle, and faster switching on and off. Solar traffic lights are equipped with a rechargeable battery, a control panel, a controller that monitors the charging and discharging of the

battery, and a timer showing the remaining time until it is completely discharged. Portable options are also available for temporary organization and traffic control during repairs or during extended power outages when the main facilities are not functioning. Solar traffic lights are non-volatile devices as they do not require external power sources. They are easy to install, adjust and maintain and are characterized by a lightweight construction and a specialized algorithm for controlling the brightness of the LEDs. Besides solar traffic lights, photovoltaic panels are used to power LED road signs, signal warning lights, and footpath lighting. Solar-powered LED road signs allow easy and quick placement in the desired location, have a non-volatile power supply, have the necessary brightness to be seen from a safe distance, and have a long service life [Sravya et al., 2020]. They are used both for temporary organization of traffic and in places with difficult access to a source of electrical power. They have a built-in controller for automatic switching on and off depending on the ambient light. They can be fixed on a pole or a trolley with frequent location changes. Solar warning light signalling provides an effective way to warn road users without the need for excavation, pulling and connecting electrical cables. It can be installed over footpaths, near schools, to indicate road hazards, etc., providing security and safety for motorists, pedestrians, and cyclists. Solar footpath lighting can be part of solar street lighting [Hoang et al., 2021].

The production of electricity from wind resources in water territories reveals a significant potential for decarbonizing the energy system and provides a wide range of opportunities for the economic and infrastructural progress of coastal cities. A disadvantage of using wind energy is the need for the smart city to be located near areas with strong winds, such as coastal cities. Continued research and development in turbine technology are increasing efficiency and reducing costs. Larger and more efficient turbines capture more wind energy, making projects more economically viable. Addressing the intermittency of wind power, advances in storage technologies, such as improved batteries, allow surplus generated during periods of high wind to be saved for use when the wind is calm.

3. Challenges in integration

At the core of the smart city concept is the improvement of citizens' lives using innovation and technology. These are high-speed data networks, sensors, the Internet of Things (IoT), artificial intelligence, cloud technologies, geographic systems, visualizations, and other technologies that enable cities to manage themselves more efficiently and provide better services to citizens. One of the main goals of smart cities is to reduce the cost of energy, water and other resources while improving the efficiency of transport and mobility. This can be achieved by using sensors that monitor traffic and adjust traffic lights, reducing drivers' time in traffic jams. Technologies also enable better waste management for a cleaner and healthier environment. High-tech solutions exist for turning cities into greener places - from local clean energy networks to electric transport hubs and intelligent buildings. However, spreading and implementing them quickly enough to reduce climate change is challenging. Efforts to reduce greenhouse gases by moving to cleaner energy and transportation and by using natural resources more efficiently will only work if citizens are involved [Hoang et al., 2021]. In a city where many people rent rather than own homes, they can buy square meters of solar panels to be installed on the roofs of public buildings and thus support the transition of the city's energy supply to renewable sources. The main challenges in using wind energy are presented in Table 1.

Table 1. The main challenges in using wind energy

Challenge	Description	Possible Solutions
Interruptions and Grid Integration	Wind energy is variable, requiring complex control systems to balance power generation fluctuations.	Development of advanced control and energy storage systems to compensate for interruptions.
Visual and noise impact	The installation of wind turbines can have a visual impact on the landscape and cause noise disturbances.	Strategic location planning, community engagement, and improvement of technologies to reduce noise
Bird and bat mortality	Modern wind turbines have reduced, but not completely eliminated, mortality among birds and bats	Ongoing research and development of technologies to minimize impacts on bird and bat populations

Municipalities can support productive users by providing public spaces or encouraging other private buildings or landowners to offer spaces that can be used for citizen-initiated energy production. These can include rooftops of schools, hospitals, apartments, or unused land that can be used to install solar panels or other renewable energy technologies. Local authorities can also offer targeted financial incentives to companies to encourage citizen participation and stimulate public engagement in energy planning. Municipalities can also serve as information centres and contribute to building the right skills to help those interested in installing renewable energy sources. Each city is unique, but some common characteristics are a favourable environment for consumer production, different from more rural-type areas [Hoang et al., 2021]. The establishment of consumer generation in cities is more complex than in rural areas due to the limited space for energy production and the more complicated conditions of ownership of surfaces (such as roofs in apartment blocks). Cities are more densely populated than rural areas, so rooftop solar technology is preferred for renewable energy generation. Moreover, due to the high population density, district heating networks are more profitable because they offer the potential to develop initiatives for producer users related to district heating networks in cities. More people live in blocks of flats, opening opportunities for collective action but making coordinating investment harder. Short distances make cities ideal for the use of electric vehicles, both private and public. Urban concepts for productive users are more likely to include connectivity with mobility [Renewables (em)power smart cities, 2022]. Cities can offer opportunities to develop integrated energy districts, for example, by redeveloping areas in a particular town or by adding new areas. Off-site electricity generation (off-site generation) opens opportunities for generating consumers to overcome the lack of space [Razmjoo et al., 2022].

4. Prospects for development and innovation

In recent years, the problems related to climate change and global warming have grown increasingly, which necessitates approaches and methods related to zero energy and decarbonization. When discussing renewable energy, including solar power generation, we should consider two key concepts - a zero-energy house and a zero-energy building. They refer to energy-efficient building design and structure, which have been proven to reduce annual energy consumption to virtually zero. More and more people are investing in a house with zero energy

consumption [Abedinia et al., 2023]. It is a house that achieves significant energy savings while preserving the quality of the indoor environment by significantly improving the facade's insulation characteristics, introducing highly efficient equipment systems, and introducing the use of different energy sources, such as photovoltaic production of energy. The goal of the zero-energy house is to achieve a zero annual balance of primary energy consumption. The zero-energy building aims to achieve a zero-energy balance. Since it is impossible to stop the operation of lighting, air conditioning, office equipment and production facilities, energy consumption is reduced through energy conservation [Razmjoo et al., 2022]. Energy consumption that cannot be completely reduced can be covered by renewable energy. The main advantage of a zero-energy building is that it can increase the effect of lowering utility costs. If a high degree of insulation and airtightness is achieved by renovating the building, the time during which the air conditioning system is used can easily be reduced. In addition, if a structure is created that allows sunlight to enter quickly, it is possible to reduce the frequency of use of lighting fixtures. A zero-energy building saves energy and leads to balanced environmental management by reducing greenhouse gases. Such management and activities can improve the value of buildings [Razmjoo et al., 2022].

5. Case studies and examples from practice

Smart buildings symbolize the advancement of modern infrastructure and their interaction with automated control systems, data processing, and artificial intelligence. Smart buildings are becoming more common as they provide various valuable services. Table 2 shows examples of smart buildings from Europe, Asia and America [Abedinia et al., 2023].

Table 2. Examples of smart buildings from Europe, Asia and America

Building Name	Location	Type	Key Smart Features
The Edge	Amsterdam, Netherlands	Office	"Net zero" energy from 100% renewable sources; 4,200 square meters of solar panels; Charging stations for electric cars; 500 bicycle parking spaces
800 FULTON MARKET	Chicago, IL, USA	Mixed-use	LEED Platinum, WELL Gold, SmartScore Platinum, WiredScore Platinum certifications; Over 8,000 IoT sensors for occupancy data; Cloud-based management platform connecting 12 building systems
Algenhaus	Hamburg, Germany	Residential	World's first facade made of bioreactors; Insulating and energy-producing façade; Algae grown for biogas production, usable for fuel or heating
Smart Houses	Fujisawa, Japan	Residential	Smart grid infrastructure; Solar panels on each home; "ECO-CUTE" heat pump powered hot water system; "ENE-FARM" fuel cell home generator

Examples of intelligent buildings in Bulgaria are, unfortunately, not a common phenomenon since the construction and purchase of such a property initially requires more significant investments. Still, on the other hand, at a later stage, smart buildings allow high returns related to energy efficiency and the optimization of energy consumption.

According to new European Union regulations, from 2030, all new buildings must be carbon neutral, and from 2050, all existing buildings must already be carbon neutral [DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast), 2024]. This raises the question of whether Bulgaria is ready for the transition to neutrality and for considering additional measures and policies to accelerate and promote energy efficiency and the active involvement of local authorities. For this purpose, the implementation of the following measures, as given in Table 3, is recommended.

Table 3. Measures and policies to accelerate and promote energy efficiency and the active involvement of local authorities

Measure	Objective	Expected Outcome
Encouraging the development of innovation and new technologies	To foster an environment that supports technological advancements	Accelerated innovation and adoption of new technologies in various sectors, leading to reduced carbon emissions
Promoting digitization and open data on greenhouse gas emissions information	To enhance transparency and encourage decarbonisation in corporate governance	Improved corporate strategies towards decarbonisation, driven by accessible and transparent emissions data
Establish an accreditation plan/system	To recognize and encourage businesses contributing to decarbonization with regional resources	Increased business participation in decarbonization efforts, leveraging regional renewable resources
Reducing energy demand by improving energy efficiency in industry and buildings	To decrease energy consumption across sectors	Significant reductions in energy demand, leading to lower greenhouse gas emissions and enhanced sustainability
Increase municipalities' role in energy and climate policies	To ensure robust local-level policy-making and coordination in energy and climate matters	Strengthened local policies and actions towards energy efficiency and climate change mitigation, with enhanced coordination among municipalities

With the advancement of intelligent buildings and technology, we not only embrace innovation and convenience but also take a proactive step towards environmental protection. These intelligent solutions align with sustainability goals, contributing to reducing carbon emissions and a greener and well-balanced climate.

Conclusion

This report emphasizes the essential role that renewable energy sources play in the development of sustainable and efficient future cities. Efforts to reduce energy consumption, utilize renewable energy, and build smart cities are at the forefront of modern societal priorities. Investment decisions are heavily influenced by factors such as cost-effectiveness, environmental impact, and reliability. There is a growing global dedication to combating climate change, with significant innovations in smart city technologies, green energy solutions, and energy efficiency emerging from both the research community and industry.

Renewable energy sources like solar, wind, hydro, and geothermal hold substantial potential for producing clean and abundant energy, free from the harmful emissions associated with fossil fuels. It is crucial to recognize the importance of these energy sources and the vital function of smart meters in harnessing their full potential. Overcoming the challenges and seizing the opportunities provided by renewable energy will pave the way for creating brighter and more sustainable urban environments that cater to the needs of today's society and future generations.

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