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Research paper doi: 10.30822/arteks.v10i2.4308

Using the Internet of Things (IoT) technology to transform urban systems and related solutions

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ARTICLE INFO

Article history:
Received March 24, 2025
Received in revised form April 17, 2025
Accepted June 18, 2025
Available online August 01, 2025

Keywords:
Cybersecurity
Digital transformation
Internet of things
Smart cities
Urban infrastructure

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ABSTRACT

The purpose of the study is to analyze the impact of IoT on the development of smart cities and urban infrastructure, as well as to develop proposals for the effective use of these technologies. It has been established that the greatest effect from the implementation of IoT is achieved in the areas of transport logistics, environmental monitoring, energy management, and public safety, which confirms the feasibility of using sensor networks for operational data collection. An important direction is the combination of IoT with artificial intelligence systems for predictive analysis of transport flows, the state of engineering networks and environmental indicators. It was determined that the implementation of IoT contributes to increasing the efficiency of resource use, reducing operating costs, improving the quality of city services and creating the prerequisites for the digital transformation of municipal management. The practical significance of the results obtained lies in the possibility of applying the proposed approaches in the development of digital development programs for cities, as well as in the creation of comprehensive platforms for monitoring urban infrastructure taking into account the requirements for cybersecurity, equipment compatibility and personal data protection.

Introduction

Global digitalization in all respects of modern cities, from transport, energy networks to public safety is fundamentally tied with the process of development of modern cities. Modern needs for speed of decision making and effective response to critical situations make traditional approaches to the management ineffective. In all of this space the predominant technology is Internet of Things (IoT), capable of automatically receiving, processing and using data for the day-to-day management of an urban sector but also the medium to long term planning of urban development.

Bhardwaj et al. (2024) indicate that the monitoring and managing all parts of urban life are possible through creating comprehensive digital platform by using IoT. According to Singh et al. (2022), integration of IoT with artificial intelligence systems leads to an increase in the accuracy of traffics flow forecasting as well as optimal operation of municipal services. Bajpai et al. (2024) demonstrated that proper use of IoT technologies in air quality and water supply monitoring systems can significantly reduce the resource losses and improve the city's environmental situation. In their work, Omrany et al. (2024) study the obstacles towards the large-scale execution of IoT in urban infrastructure, namely the obstacles of platform interoperability, cybersecurity, and digital inequality.

The aim of the study is to conduct a systemic analysis of the effect of Internet of Things (IoT) technologies on the city development and city infrastructure, find out key areas for incorporating IoT solutions to the systems of urban management, and suggest ways for improving the effectiveness and the security in IoT usage in the city. The research hypothesis posits that IoT technologies can be positioned as an effective tool for optimizing urban systems. The following tasks were set for this goal: defining main service areas of IoT in the city, technological trend and obstacle in realization of IoT solution, the role of IoT in promoting an urban infrastructure potential usage for the purpose of sustainable development of urban infrastructure, and the directions of the further research in this field.

Literature review

Further studies took place in relation with the Internet of Things (IoT) and on the operation of a smart city through the study of introducing network of sensors, artificial intelligence and blockchain, which help to increase the efficiency of urban infrastructure as well as strengthen transparency in government (Alam et al. 2024; Bajpai et al. 2024; Guo, Huang, and Xu 2024; Sehgal, Saxena, and Shah 2025). Indeed, key challenges in the use of IoT platforms include cybersecurity, data privacy and lack of unified technical standards (Aga et al. 2024; Chmyr et al. 2023; Soleimani Borujerdi, Sanahmadi, and Abdollahi Azgomi 2025; Ullo and Sinha 2020). The works of Bajpai et al. 2024; Sunny et al. (2020) study the aspects of application of IoT for air quality monitoring, transport management and energy consumption optimization, giving an opportunity to reduce the environmental loading. The importance of comprehensive approach towards smart cities along with the integration of IoT with Big data technologies, 5G communications technologies and the cloud computing is emphasized in Omrany et al. (2024); Rai et al. (2023).

Jacques et al. (2024) investigate the adoption of smart city actions into urban planning, in terms of management of urban environment through thematic areas. In addition, they discuss the need for strategic planning and policy development aimed to structure the inclusion of digital technologies in the urban environment (Jacques et al. 2024).

Finally, a separate block of research is dedicated to the advantages of the implementation of IoT in the urban environment – a rapid rise of investment in the digital infrastructure, improvement of the quality of life, and increase in the number of opportunities for entrepreneurship (Quasim et al. 2023; Setiawan et al. 2022; Li 2023; Havrysh et al. 2020; Jiang 2020). Secondly, as Malik et al. (2021); Sehgal, Saxena, and Shah (2025) note, implementation of IoT can entail increasing cities' dependence on technology providers and digital inequality, as well as an abuse of personal data.

Liu et al. (2023) consider the role of IoT in building smart healthcare systems. Duguma and Bai (2024) explore the potential of IoT in increasing the efficiency of agricultural production through monitoring soil conditions, weather and automation of irrigation systems, which is also relevant for agglomerations where maintaining food security is a priority.

The issues of ensuring energy efficiency and reliability of urban systems through the use of smart grids and IoT solutions are highlighted in the works of Havrysh et al. (2020); Soleimani Borujerdi, Sanahmadi, and Abdollahi Azgomi (2025). Dotsenko and Batsurovska (2022) considers the degree to which lifelong learning can be applied to the training of energy engineers in relation to the necessity of developing digital competencies in working with IoT systems, which, in turn, are becoming widespread in the urban infrastructure and energy sectors. STEM study is an important part of training future engineers in the digital age and development of competencies to enter modern technological reality (Олійник et al. 2020; Bhardwaj et al. 2024). Wirtz (2024) looks at the digital transformation of business using IoT and, in

particular, shows the importance of IoT both for smart cities and as a tool to develop new business models.

Although smart cities have done much in practice in IoT market implementations, issues of integrated unity of different technology platforms, and reliable data protection in the face of increasing the number of connected devices and cyber challenges, have yet to be solved.

Methods

The analysis method was used in the research to evaluate the trends of IoTex solutions implementation in smart cities and also scientific publications, reports of international analytical agencies, and forecasts of the industry research. Processing of the data was carried out by systematization and generalization methods to determine the main development areas of Internet of Things technologies in urban infrastructure, identify problems, and prospects for future implementation. The dynamics of global investments in IoT for smart cities were paid special attention to enabling the assessment of the level of interest of governments, municipalities and business for development of digital solutions for urban management.

The deployment of IoT in smart infrastructure is being carried out through modern approaches as decentralized computing, artificial intelligence and resilient communication network building.

1. *Choose a centralized, edge, or fog computing*. It helps to improve the transportation system management, decrease the network load, and enable more timely response to the changing urban situations.
2. *Artificial Intelligence (AI) and Machine Learning (ML) for Urban Analytics*. Nowadays, AI and ML algorithms are becoming integrated into urban IoT systems to predict the infrastructure loads, optimize energy consuming, and enhance safety.
3. *Blockchain enables the Mettle to enhance IoT security*. An important aspect of IoT security in smart cities is chain, blockchain. This will make it possible for transaction data to be stored in an immutable way so as to insure transparency and reliability of information.
4. *The communication infrastructure*: 5G and LPWAN. A reliable communication network is necessary for the effectual working of urban IoT solutions. Devices with low power consumption such as sensors in water supply and energy, which at the same time use LPWAN (Low Power Wide Area Network) solutions, including LoRaWAN and NB-IoT.
5. *Smart resource management and urban services*. The water supply system uses IoT to pinpoint, monitor, and detect leaks and pipeline condition in real time.
6. *Smart transport and mobility digital infrastructure*. Autonomous vehicles and car sharing also utilize IoT which helps in the development of sustainable mobility and in the reduction of CO_2 emissions.

Results and discussion

The modern cities are facing huge challenges. It enables operation monitoring, forecasting and optimization of key city systems' operation, that increase the efficiency of management process and improve the quality of residents' life (Okafor, Alghorani, and Delaney 2020).

Such approaches allow for timely detection of emergency situations, optimization of logistics, reduction of energy consumption and increase of security at the city level (Bajpai et al. 2024). The table below summarizes the main directions of implementation of IoT solutions.

Table 1. The impact of IoT solutions on the efficiency of urban systems management

Scope of implementation	IoT solutions	Impact on efficiency
Resource management (water, waste)	Smart water meters, garbage tank filling sensors, automated leak monitoring systems	Reducing resource losses, optimizing waste collection schedules, increasing control over consumption (Bajpai et al. 2024)
Transportation systems	Intelligent traffic management systems, parking lot sensors, public transport monitoring	Reducing congestion, optimizing routes, increasing transport accessibility (Alam et al. 2024)

Scope of implementation	IoT solutions	Impact on efficiency
Energy networks	Smart Grids, load forecasting systems, integration of renewable energy sources	Increasing the stability of energy supply, reducing losses, balancing energy consumption (Sehgal, Saxena, and Shah 2025)
Security systems	Video surveillance networks with analytics, air quality monitoring sensors, emergency notification systems	Improving public safety, responding quickly to threats, monitoring environmental indicators (Guo, Huang, and Xu 2024)

Source: Created by authors based on (Bajpai et al. 2024; Alam et al. 2024; Sehgal, Saxena, and Shah 2025; Guo, Huang, and Xu 2024).

The introduction of intelligent sensors, smart meters and automated data processing systems creates conditions for the efficient use of resources and ensures timely detection of critical situations. Figure 1 presents a generalized diagram of the main socio-economic aspects of the implementation of IoT in smart cities, which reflects the relationship between the digitalization of urban infrastructure, improving the quality of life, creating new jobs and developing an innovative business environment.

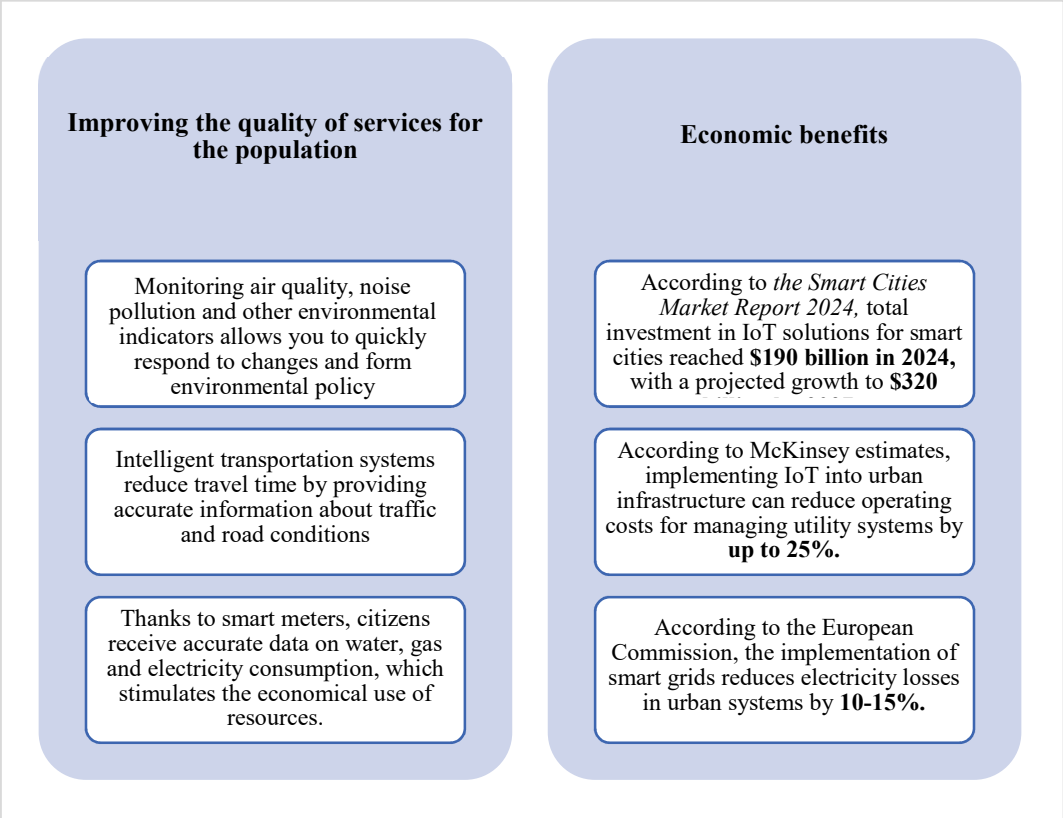

Figure 1. Socio-economic aspects
Source: Created by authors based on (Bajpai et al. 2024; Alam et al. 2024; Sehgal, Saxena, and Shah 2025).

Attracting funding is a key factor in scaling such projects, as the creation of smart monitoring, management and analytics systems requires significant capital investments (Бояринова and Бичковська 2020; Lüdeke-Freund 2020). Global investments in this area demonstrate dynamic growth, reflecting the growing interest of governments, municipalities and the private sector in the development of innovative urban technologies (Ighalo, Adeniyi, and Marques

2021; Salam 2020). To analyze the dynamics of investments (figure 2), data from reports of international analytical agencies, scientific publications and industry research forecasts were used. The collected data were processed using comparative analysis methods.

Special attention is paid to the structure of investments by direction.

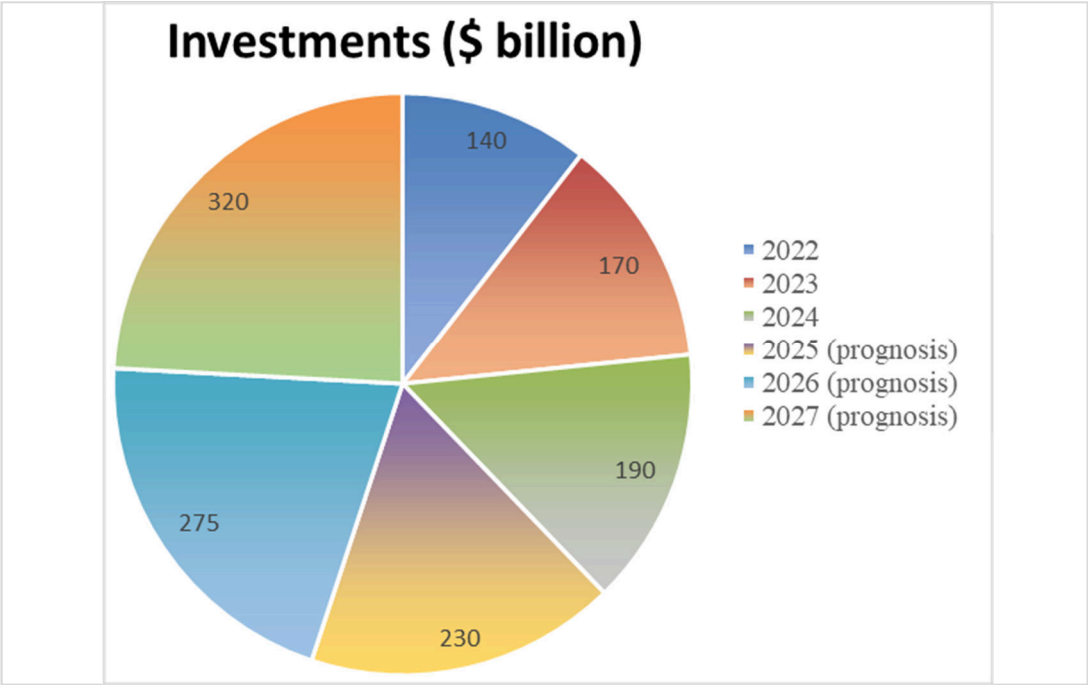

Figure 2. Global investment in IoT for smart cities ($ billion)
Source: Created by authors based on Alam et al. (2024); Bajpai et al. (2024); Sehgal, Saxena, and Shah (2025)

Analysis of the presented data indicates a steady growth trend in global investments in recent years. In particular, in the period from 2020 to 2024, the volume of financing almost doubled - from approximately $ 120 billion in 2020 to over $ 230 billion in 2024. The average annual growth rate of investments is about 15-17%, which indicates a high level of interest from public and private investors. A particularly noticeable acceleration of investment processes was recorded in 2023-2024, when investment volumes increased by $ 28 billion compared to the previous year.

Not without attention is the reduction of emissions and energy consumption. Smart lighting (automatic brightness adjustment based on the level of lighting and movement) reduces the energy consumption of lighting systems by up to 35% (Omrany et al. 2024; Nižetić et al. 2020).

Figure 3 shows the dynamics of reducing CO_2 emissions in cities that are actively implementing IoT systems.

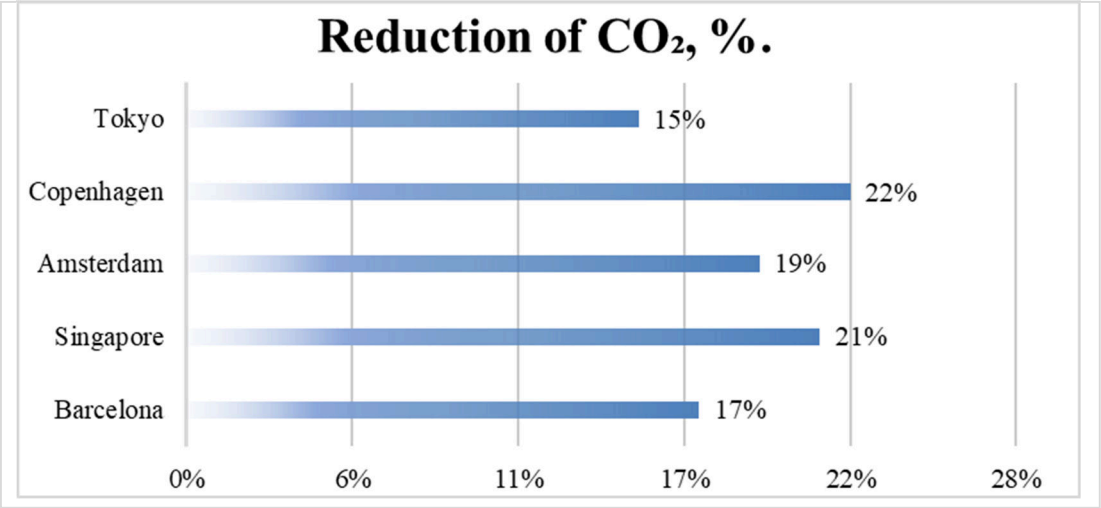

Figure 3. CO_2 emission reduction in cities with developed IoT systems (% of baseline)
Source: created by authors based on Bajpai et al. (2024); Guo, Huang, and Xu (2024); Omrany et al. (2024).

Analysis of numerical data shows that the implementation of IoT solutions allows achieving an average reduction in CO_2 emissions of 15-20%. The highest indicators were achieved in cities with an integrated approach to smart transport management, where emissions are reduced by up to 22% compared to the baseline. In cities where IoT is used mainly for energy monitoring, the level of emission reduction is about 12-14%. In general, in cities with a high level of digitalization, an average reduction in CO_2 emissions of 18% was achieved.

The integration of sensors, smart meters, video surveillance cameras, air quality and energy consumption monitoring systems create a single information environment for analyzing and forecasting urban processes. Figure 4 shows the projected growth dynamics of the number of connected IoT devices in urban infrastructures by 2025.

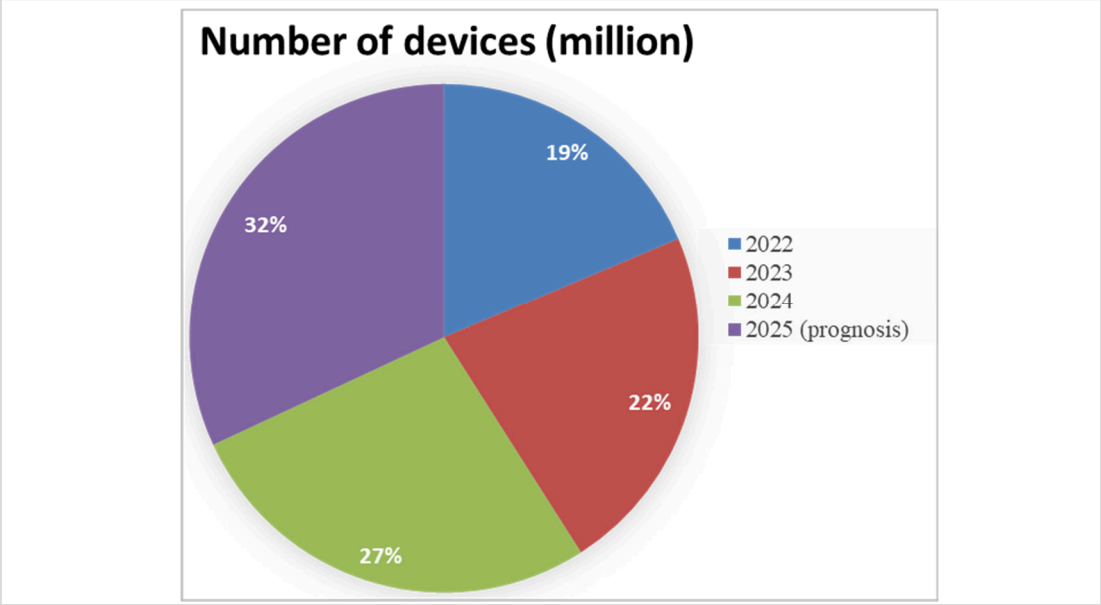

Figure 4. Number of connected IoT devices in cities by 2025 (million units)
Source: Created by authors based on Omrany et al. (2024); Alam et al. (2024); Guo, Huang, and Xu (2024); Bajpai et al. (2024).

Analysis of the presented data shows the rapidly growing. If in 2020 this figure was about 380 million devices, then according to forecasts by the end of 2025 their number will exceed 800 million units. In five years, the increase is more than 110%, which indicates an accelerated digital transformation of urban spaces. The greatest growth is observed in the segment of environmental monitoring systems, intelligent transport and smart energy grids, where the number of devices is growing by an average of 18-22% each year.

The IoT forms the basis for *digital ecosystems of smart cities*, integrating infrastructure, economic processes into a single information space.

Key threats include cybersecurity issues, data protection, technical limitations, lack of common standards and social risks associated with citizens' trust in new technologies (Aga et al. 2024; Sehgal, Saxena, and Shah 2025). In view of this, a comprehensive risk assessment and development of multi-layered protection systems are necessary at the design and implementation stage of IoT solutions.

Table 2. Main challenges and risks of implementing IoT in urban infrastructure

Risk category	Description	Consequences
Cybersecurity	Vulnerability of IoT devices to hacker attacks, insufficient level of protection of communication channels, lack of security updates	Seizing control over urban lighting, transportation, or energy grid systems, creating chaos and man-made threats (Aga et al. 2024)
Data protection and privacy	Accumulation of huge amounts of citizens' personal data, lack of anonymization and access control mechanisms	Leakage of confidential information, data misuse, formation of “digital profiles” without the consent of residents (Alam 2023)
Lack of uniform technical standards	Fragmentation of approaches to building IoT networks, use of incompatible equipment and communication protocols	Inability to create a single urban system, increasing integration costs (Sehgal, Saxena, and Shah 2025)
Reliability of equipment and networks	Limited sensor lifespan, data transmission errors, failures in cloud processing systems	Data loss or corruption, incorrect management decisions, reduced trust in systems (Soleimani Borujerdi, Sanahmadi, and Abdollahi Azgomi 2025)
Ethical and social risks	Constant monitoring of citizens, risks of "digital discrimination", formation of a "social rating system"	Deterioration of social trust, protest moods, blocking of new initiatives (Chmyr et al. 2023)
Financial risks	High cost of infrastructure modernization, dependence on technology suppliers	Unjustified costs, corruption risks, financial instability of municipalities (Omrany et al. 2024)

Source: Created by the author based on Omrany et al. (2024); Aga et al. (2024); Alam (2023); Sehgal, Saxena, and Shah (2025); Soleimani Borujerdi, Sanahmadi, and Abdollahi Azgomi (2025); Chmyr et al. (2023).

Social factors play a separate role - the level of trust of citizens in monitoring systems, awareness of the collection and processing of their data, as well as ethical issues related to the formation of digital profiles and their use for making management decisions.

Case Study: Using IoT in a Smart City Singapore. Singapore is one of the world’s leading cities in implementing IoT technologies to develop urban infrastructure. Through a comprehensive approach to digital transformation, the city has integrated IoT solutions into transportation systems, energy management, healthcare, and security (Sim and Lee 2022; Caburn Telecom 2023).

1. *Transport and mobility*. Traffic monitoring is done in real time, through an Intelligent Transport System (ITS) which is a Singaporean implementation using IoT sensors. Using sensors, GPS navigators and cameras the artificial intelligence works to optimize traffic lights and public transport route.

2. *Smart energy consumption*. Members of the Smart Nation project in Singapore have invented IoT to realize energy efficiency. The city is also working to develop smart lighting installations that automatically adjusts the brightness the light levels and the later use of streets.
3. *Environmental monitoring and sustainable development*. The IoT solutions enable the city to react quickly to environmental challenges and reduce the negative effect of urbanization on the environment.
4. *Smart buildings and infrastructure*. The concept of 'smart' housing complexes being marketed by the Singapore government.
5. *Public safety and health*. The city operates a video surveillance system with elements of artificial intelligence, which analyzes the flows of people and vehicles to identify potential threats. IoT devices have been introduced for remote monitoring of the condition of patients, which allows for a faster response to emergencies (Sim and Lee 2022; Caburn Telecom 2023).

Let's consider recommendations with descriptions for improving regulatory support, technical standards, and IoT implementation strategies in smart cities:

1. *Development of a single regulatory framework for regulating IoT in urban infrastructure*. Effective implementation of IoT is impossible without the creation of a comprehensive legislative framework that would take into account the peculiarities of the functioning of distributed networks, data storage and processing, as well as liability for cyberattacks and information leaks (Sehgal, Saxena, and Shah 2025).
2. *Implementation of unified technical standards for IoT platforms in cities*. The state should approve technical standards for IoT devices, network protocols, data exchange formats and security requirements. In particular, this will ensure solution compatibility among vendors, system scaling and lowering the cost of adding new component to the existing infrastructure (Soleimani Borujerdi, Sanahmadi, and Abdollahi Azgomi 2025).
3. *Develop a national strategy for the safe implementation of IoT in smart cities*. Security of such systems should be a thing to pay particular attention to: the creation of threat detection early systems, mandatory security audits for critical systems, the introduction of mechanisms for certification for IoT devices. Close interaction among the state, cities, technology companies and the public should be provided by the strategy (Aga et al. 2024).
4. *Introduction of public-private partnership mechanisms for the development of IoT infrastructure*. The IoT development can be supported by PPP's creation and, therefore, businesses can invest in such projects in transparent conditions with the relief that the expense will be covered and come with a guarantee of return on the investment (Omrany et al. 2024).

The novelty of the research lies in the proposal to use IoT technology to transform urban systems and related solutions in the context of environmental innovation in the modern economic environment. This approach is considered an effective tool for optimizing the environmental and socio-economic environment of urbanized systems, positioning itself as one of the leading concepts for achieving full implementation of sustainable development principles.

The approach proposed in the study can contribute to solving the problem of reducing the consumption of exhaustible resource potential, ensuring preventive protection and regeneration of the environment, stimulating the development of economic entities and public-private partnerships. The integration of ecological and economic principles of IoT use in combination with management incentives will enable the implementation of a practical concept of rational management of the urban environment and natural resources.

Discussion

There is a degree of polarization in how IoT cybersecurity should be achieved. For instance, (Aga et al. 2024; Sehgal, Saxena, and Shah 2025) recommend that we should take the path of decentralized protection, in particular through block chain and distributed authentication system. In fact, Косович (2021) stress that the strengthening of state control of protection of critical infrastructures and the formation of a single system of cyber protection at the state level is necessary.

Yermachenko (2023); Omrany et al. (2024) focus on the positive effects. Chmyr et al. (2023) draw attention to the risks of digital inequality, when part of the population remains outside the

scope of access to new digital services. Comparison of the results obtained with the studies of Chen et al. (2024); Zhang and Feng (2025) shows that the response speed of urban systems increases significantly due to the introduction of edge computing and decentralized data processing platforms. This is consistent with our findings regarding the need to minimize delays in critical areas – transport management, security and environmental monitoring.

Of great interest are the results of Bhardwaj et al. (2024) research on global trends in IoT development for smart cities, where a trend is noted to combine IoT with big data and AI to provide predictive analytics. Our results confirm this trend, as the combination of IoT and AI turned out to be the most effective in predicting traffic flows and managing energy networks. However, the study revealed certain limitations. In particular, the dynamics of IoT implementation in different cities differ significantly depending on the level of digital readiness, political will and investment opportunities, which is confirmed by the data of Guo, Huang, and Xu (2024); Sehgal, Saxena, and Shah (2025).

Given the above, it is advisable to focus further research on developing unified standards for integrating IoT solutions into urban infrastructure, as well as on creating adaptive digital transformation models that take into account the level of readiness of specific cities for IoT implementation.

Conclusions

The implementation of IoT technologies in smart cities creates fundamentally new opportunities for monitoring, managing and forecasting urban processes, ensuring the transition to flexible and adaptive urban management systems. The data obtained indicate that the greatest potential of IoT is realized in the areas of transport, energy, environmental security, which is partially consistent with previous studies. The novelty of the results lies in identifying critical factors for the successful implementation of IoT at the municipal level, in particular through the creation of integrated platforms for collecting and analyzing data in real time from many sources. The practical significance of the study lies in the development of proposals for harmonizing technical standards, strengthening cybersecurity requirements and forming a state policy for the digital transformation of cities with the involvement of the public and business. The study analyzed mechanisms for ensuring sustainable development of urbanized areas through environmental innovation measures, identified the functionality of environmental monitoring, and analyzed trends in its implementation through IoT.

The study proved that the priority areas of development in the field under investigation are implementing a number of measures within a single sustainable development strategy. The proposed concept provides for the complementary implementation of IoT elements to a sustainable climate course and the increased efficiency of renewable energy resources.

It is these innovative approaches that can ensure the upgrade of the concept of urban systems development. In this context, a new discovery is the dependence of the energy efficiency of cities and the environmental sustainability of urbanized areas on the level of integration of IoT tools.

At the same time, the limitation of this study is the different availability and quality of data from individual cities, which makes it difficult to build universal models for assessing the effectiveness of IoT solutions.

Further research should be directed at developing adaptive scenarios, taking into account the economic, technological and social characteristics of each city, as well as at creating methods for assessing the economic efficiency and social impact of such technologies. Special attention should be paid to studying the impact of new generations of communication, in particular 6G, on the ability of IoT systems. Also, the potential of blockchain technologies in the context of urban development security deserves due attention. The contribution of this study lies in confirming the hypothesis that IoT technologies are an effective tool for optimizing urban systems.

References

Aga, Dagmawit Tadesse, Rakesh Chintanippu, Rawshan Ara Mowri, and Madhuri Siddula. 2024. “Exploring Secure and Private Data Aggregation Techniques for the Internet of Things: A Comprehensive Review.” *Discover*

Internet of Things 4 (1): 28. https://doi.org/10.1007/s43926-024-00064-7.

Alam, Tanweer. 2023. "Blockchain and Big Data-Based Access Control for Communication Among IoT Devices in Smart Cities." *Wireless Personal Communications* 132 (1): 433–56. https://doi.org/10.1007/s11277-023-10617-8.

Alam, Tanweer, Ruchi Gupta, N. Nasurudeen Ahamed, Arif Ullah, and Ahmed Almaghthwi. 2024. "Towards Sustainable IoT-Based Smart Mobility Systems in Smart Cities." *GeoJournal* 89 (6): 235. https://doi.org/10.1007/s10708-024-11227-y.

Bajpai, Anju, T. P. Girish Kumar, G. Sreenivasan, and S. K. Srivastav. 2024. "System Design, Automatic Data Collection Framework and Embedded Software Development of Internet of Things (IoT) for Air Pollution Monitoring of Nagpur Metropolis." *Journal of the Indian Society of Remote Sensing* 52 (10): 2347–59. https://doi.org/10.1007/s12524-024-01943-w.

Batsurovska, I. 2023. "Education of energy engineers in the context of lifelong learning." In *Proceedings of the 4th International Conference on History, Theory, and Methodology of Learning*, Kryvyi Rih, Ukraine, 2023: 5–12. https://doi.org/10.1088/1755-1315/1049/1/012047

Bhardwaj, Vivek, A. Anooja, Lovkesh Singh Vermani, Sunita, and Balwinder Kaur Dhaliwal. 2024. "Smart Cities and the IoT: An In-Depth Analysis of Global Research Trends and Future Directions." *Discover Internet of Things* 4 (1): 19. https://doi.org/10.1007/s43926-024-00076-3.

Caburn Telecom. 2023. *IoT in Singapore: Applications, benefits & challenges*. https://caburntelecom.com/iot-in-singapore/

Chen, Chao, Liwu Gong, Xin Luo, and Fuwang Wang. 2024. "Research on a New Management Model of Distribution Internet of Things." *Scientific Reports* 14 (1): 995. https://doi.org/10.1038/s41598-024-51570-1.

Chmyr, Yaroslav, Anastasia Nekryach, Larysa Kochybei, Alla Dakal, and Lilia Strelbytska. 2023. "Postindustrial Society and Global Informational Space as Infrastructure Medium and Factor for Actualization of the State Informational Security." In, 61–73. https://doi.org/10.1007/978-3-031-33724-6_4.

Dotsenko, N A, and I V Batsurovska. 2022. "Estimation of Efficiency of Use of Water-Lifting Equipment in Technological Processes of Agricultural Production." *IOP Conference Series: Earth and Environmental Science* 1049 (1): 012047. https://doi.org/10.1088/1755-1315/1049/1/012047.

Duguma, Amenu Leta, and Xiuguang Bai. 2024. "How the Internet of Things Technology Improves Agricultural Efficiency." *Artificial Intelligence Review* 58 (2): 63. https://doi.org/10.1007/s10462-024-11046-0.

Guo, Huichao, Runhua Huang, and Zhiming Xu. 2024. "The Design of Intelligent Highway Transportation System in Smart City Based on the Internet of Things." *Scientific Reports* 14 (1): 28122. https://doi.org/10.1038/s41598-024-79903-0.

Hashem, I. A., Siddiqa, A., Alaba, F. A., et al. 2024. "Distributed intelligence for IoT-based smart cities: A survey." *Neural Computing and Applications* 36(1), 16621–16656. https://doi.org/10.1007/s00521-024-10136-y

Havrysh, Valerii, Vasyl Hruban, Oleksiy Sadovoy, Ilona Batsurovska, Valentyna Fedorchuk, and Katerina Yablunovskaya. 2020. "Energy Saving Technologies for Automatical Move Irrigation Equipment." In *2020 IEEE Problems of Automated Electrodrive. Theory and Practice (PAEP)*, 1–4. IEEE. https://doi.org/10.1109/PAEP49887.2020.9240881.

Ighalo, Joshua O., Adewale George Adeniyi, and Goncalo Marques. 2021. "Internet of Things for Water Quality Monitoring and Assessment: A Comprehensive Review." In, 245–59. https://doi.org/10.1007/978-3-030-51920-9_13.

Jacques, Elizeu de Albuquerque, Alvaro Neuenfeldt Júnior, Sabine de Paris, Matheus Binotto Francescatto, and Raquel Francieli Bilhalva Nunes. 2024. "Smart City Actions Integrated into Urban Planning: Management of Urban Environments by Thematic Areas." *Applied Sciences* 14 (8): 3351. https://doi.org/10.3390/app14083351.

Jiang, Dingfu. 2020. "The Construction of Smart City Information System Based on the Internet of Things and Cloud Computing." *Computer Communications* 150 (January):158–66.

https://doi.org/10.1016/j.comcom.2019.10.035.

Li, Conghui. 2023. "Development of IoT Smart Cities and Optimization of English Education Systems Based on 5G Networks." *Soft Computing*, June. https://doi.org/10.1007/s00500-023-08823-4.

Liu, Yang-Yang, Ying Zhang, Yue Wu, and Man Feng. 2023. "Healthcare and Fitness Services: A Comprehensive Assessment of Blockchain, IoT, and Edge Computing in Smart Cities." *Journal of Grid Computing* 21 (4): 82. https://doi.org/10.1007/s10723-023-09712-8.

Lüdeke-Freund, Florian. 2020. "Sustainable Entrepreneurship, Innovation, and Business Models: Integrative Framework and Propositions for Future Research." *Business Strategy and the Environment* 29 (2): 665–81. https://doi.org/10.1002/bse.2396.

Malik, Praveen Kumar, Rohit Sharma, Rajesh Singh, Anita Gehlot, Suresh Chandra Satapathy, Waleed S. Alnumay, Danilo Pelusi, Uttam Ghosh, and Janmenjoy Nayak. 2021. "Industrial Internet of Things and Its Applications in Industry 4.0: State of The Art." *Computer Communications* 166 (January):125–39. https://doi.org/10.1016/j.comcom.2020.11.016.

Okafor, Nwamaka U., Yahia Alghorani, and Declan T. Delaney. 2020. "Improving Data Quality of Low-Cost IoT Sensors in Environmental Monitoring Networks Using Data Fusion and Machine Learning Approach." *ICT Express* 6 (3): 220–28. https://doi.org/10.1016/j.icte.2020.06.004.

Omrany, Hossein, Karam M. Al-Obaidi, Mohataz Hossain, Nayef A. M. Alduais, Husam S. Al-Duais, and Amirhosein Ghaffarianhoseini. 2024. "IoT-Enabled Smart Cities: A Hybrid Systematic Analysis of Key Research Areas, Challenges, and Recommendations for Future Direction." *Discover Cities* 1 (1): 2. https://doi.org/10.1007/s44327-024-00002-w.

Quasim, Mohammad Tabrez, Khair ul Nisa, Mohammad Zunnun Khan, Mohammad Shahid Husain, Shadab Alam, Mohammed Shuaib, Mohammad Meraj, and Monir Abdullah. 2023. "An Internet of Things Enabled Machine Learning Model for Energy Theft Prevention System (ETPS) in Smart Cities." *Journal of Cloud Computing* 12 (1): 158. https://doi.org/10.1186/s13677-023-00525-4.

Rai, Hari Mohan, Atik-Ur-Rehman, Aditya Pal, Sandeep Mishra, and Kaustubh Kumar Shukla. 2023. "Use of Internet of Things in the Context of Execution of Smart City Applications: A Review." *Discover Internet of Things* 3 (1): 8. https://doi.org/10.1007/s43926-023-00037-2.

Salam, Abdul. 2020. "Internet of Things for Environmental Sustainability and Climate Change." In, 33–69. https://doi.org/10.1007/978-3-030-35291-2_2.

Sehgal, Naresh Kumar, Manoj Saxena, and Dhaval N. Shah. 2025. "Foundations of the Internet of Things (IoT)." In *AI on the Edge with Security*, 43–70. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-78272-5_3.

Setiawan, Roy, Maria Manuel Vianny Devadass, Regin Rajan, Dilip Kumar Sharma, Ngangbam Phalguni Singh, K. Amarendra, Rama Koteswara Rao Ganga, Ramkumar Raja Manoharan, V. Subramaniyaswamy, and Sudhakar Sengan. 2022. "IoT Based Virtual E-Learning System for Sustainable Development of Smart Cities." *Journal of Grid Computing* 20 (3): 24. https://doi.org/10.1007/s10723-022-09616-z.

Sim, S. K., and Lee, S. W. 2022. "Revolution of IoT development in the smartest city: Review of smart city development in Singapore and Hong Kong." *ResearchGate.* https://www.researchgate.net/publication/360618038_Revolution_of_IoT_Development_in_Smartest_City_Review_of_Smart_City_Development_in_Singapore_and_Hong_Kong

Singh, Rajesh, Anita Gehlot, Shaik Vaseem Akram, Amit Kumar Thakur, Dharam Buddhi, and Prabin Kumar Das. 2022. "Forest 4.0: Digitalization of Forest Using the Internet of Things (IoT)." *Journal of King Saud University - Computer and Information Sciences* 34 (8): 5587–5601. https://doi.org/10.1016/j.jksuci.2021.02.009.

Soleimani Borujerdi, Amir, Arman Sanahmadi, and Mohammad Abdollahi Azgomi. 2025. "Unified Modeling and Evaluation of Availability and Power Consumption in the Internet of Things." *Peer-to-Peer Networking*

and Applications 18 (2): 6. https://doi.org/10.1007/s12083-024-01865-x.

Sunny, Ali Imam, Aobo Zhao, Li Li, and Sambu Kanteh Kanteh Sakiliba. 2020. "Low-Cost IoT-Based Sensor System: A Case Study on Harsh Environmental Monitoring." *Sensors* 21 (1): 214. https://doi.org/10.3390/s21010214.

Ullo, Silvia Liberata, and G. R. Sinha. 2020. "Advances in Smart Environment Monitoring Systems Using IoT and Sensors." *Sensors* 20 (11): 3113. https://doi.org/10.3390/s20113113.

Wirtz, Bernd W. 2024. "Internet of Things." In *Digital Business*, 261–99. Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-41467-2_7.

Yermachenko, Volodymyr. 2023. ""Theory and Practice of Public Management of Smart Infrastructure in the Conditions of the Digital Society' Development: Socio-Economic Aspects"." *Economic Affairs* 68 (1). https://doi.org/10.46852/0424-2513.1.2023.29.

Zhang, Yongle, and Junlai Feng. 2025. "Towards a Smart and Sustainable Future with Edge Computing-Powered Internet of Things: Fundamentals, Applications, Challenges, and Future Research Directions." *Journal of The Institution of Engineers (India): Series B* 106 (2): 785–804. https://doi.org/10.1007/s40031-024-01186-w.

Бояринова, К.О., and А.А. Бичковська. 2020. "ПРОБЛЕМИ ТА ПЕРСПЕКТИВИ ВПРОВАДЖЕННЯ ЕКОЛОГІЧНИХ ІННОВАЦІЙ НА ПІДПРИЄМСТВАХ." *Підприємництво Та Інновації*, no. 14 (October), 19–24. https://doi.org/10.37320/2415-3583/14.4.

Косович, Б.І. 2021. "ЕКОЛОГІЗАЦІЯ ЯК НАПРЯМ ІННОВАЦІЙНОГО РОЗВИТКУ ПІДПРИЄМНИЦТВА." *Підприємництво Та Інновації*, no. 17 (April), 60–65. https://doi.org/10.37320/2415-3583/17.12.

Олійник, Віктор Васильович, Олександр Миколайович Самойленко, Ілона Вікторівна Бацуровська, and Наталья Андреевна Доценко. 2020. "STEM-ОСВІТА В СИСТЕМІ ПІДГОТОВКИ МАЙБУТНІХ ІНЖЕНЕРІВ." *Information Technologies and Learning Tools* 80 (6): 127–39. https://doi.org/10.33407/itlt.v80i6.3635.

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