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Economic aspects of projects based on the Internet of Things

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Abstract. The aim of this study was to examine how the implementation of Internet of Things (IoT) technologies influences economic performance by evaluating their effects on efficiency, cost reduction, and the transformation of business processes. The methodology relied on theoretical analysis of scientific sources, content analysis of technical descriptions, comparative evaluation of corporate cases, and sector-specific analytical approaches. The results showed that the IoT provides a substantial and stable increase in efficiency across sectors. In industry, digitalisation reaches 57.5%, manual actions decrease by 40-60%, and labour costs fall by about 25%. Predictive maintenance lowers unplanned downtime by 25-35% and raises productivity by 20-30%. In logistics, intelligent routing reduces transportation costs by 10-25% and delivery time by 20-25%. In agriculture, drones and sensors cut agrochemical use by 30-45% and water consumption by up to 90%, with yields increasing by 15-30%. In the energy sector, smart meters reduce electricity consumption by 2.5-3.5% and Smart Grid systems reduce network losses by 15-25%. At the macro level, the digital economy in Organisation for Economic Cooperation and Development countries grew 2.5 times faster than gross domestic product, while a 10-percentage-point increase in IoT connectivity raised total factor productivity by 0.23 percentage points. The study also identified barriers to implementation, including limited interoperability, missing standards, security risks, a shortage of specialists, unstable regulation and high investment and operating costs with uncertain returns. Enterprises and public institutions to improve efficiency and optimise resource use can apply the results

Keywords: digital infrastructure; sensor networks; real-time data; operational efficiency; investment; cybersecurity

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Introduction

The expansion of connected devices and data-driven automation is transforming production systems, urban infrastructure, logistics, healthcare, and consumer services. As companies intensify the deployment of sensor networks, cloud platforms, and intelligent monitoring tools, the economic consequences of these transformations become increasingly significant. In the digital environment, a gap persists between the rapid diffusion of technologies and the readiness of economic and social systems to integrate them. K. Abdullayev *et al*. (2024) showed that, despite notable progress in Azerbaijan's digital infrastructure, challenges remain-uneven Internet access, limited digital literacy, cyber risks and the need for stronger regulatory mechanisms. The authors noted that infrastructure upgrades, expanded e-services, digital public administration and support for innovation can accelerate economic development and modernise business processes. T. Guluzade (2025) highlighted that technological renewal in Azerbaijan is uneven, with regional disparities, a shortage of specialists, and increased cybersecurity demands, yet state strategies, e-government, fintech growth, wider telecommunications networks and platforms such as Azerbaijan Service and Assessment Network and myGov have significantly improved transparency and reduced administrative burdens. T.T. Aslanova *et al*. (2024) emphasised that expanding digital platforms, innovative technologies and e-government tools enhances productivity, reduces shadow activity, strengthens business competitiveness, improves financial mechanisms and simplifies administrative procedures.

In economic systems, a gap persists between the rapid spread of Internet of Things (IoT) technologies and the capacity of institutions and businesses to integrate them into production and management. D. Singhal *et al*. (2024) showed that IoT reshapes economic processes by increasing the role of data, intelligent systems and automated monitoring, altering cost structures and enabling productivity gains in finance, transport, logistics, agriculture, energy and urban services. The authors demonstrated that IoT reduces downtime and operating costs, improves service quality and optimises resource use, with notable effects in predictive maintenance, secure transactions, smart city infrastructure, precision agriculture and automated energy management. C. Huang *et al*. (2024) highlighted that IoT transforms household and infrastructure systems by enhancing energy efficiency, lowering operational expenses and creating opportunities for new technology-driven employment. Despite technological progress, IoT adoption in construction remains slow due to fragmented management and weak standardisation. M. Massoud *et al*. (2025) showed that IoT integration in sustainable construction is constrained by technical incompatibility, security limitations, organisational unpreparedness and skill shortages; using Exploratory Factor Analysis, Structural Equation Modelling (SEM) and Artificial Neural Network (ANN), the authors identified five barrier groups: connectivity difficulties, knowledge gaps, limited resources, organisational uncertainty and insufficient competencies.

In the context of digital transformation, there are significant challenges in ensuring consistency between the rapid development of technologies and the ability of organisations to integrate e-commerce tools, Radio Frequency Identification, automated systems, IoT and mobile platforms into daily operations. The study by K. Yogen Sevak & B. George (2024) demonstrated that the growing role of digital technologies is significantly changing the economic interaction between producers, consumers and logistics structures. The authors emphasise that IoT technologies, artificial intelligence (AI), big data and blockchain are shaping new models of value creation, increasing process efficiency and contributing to the emergence of innovative products and services.

In the field of IoT research, there is insufficient attention to how IoT technologies are changing circular economy models and affecting the environmental and economic performance of enterprises. X. Sun & X. Wang (2022), who showed that the integration of IoT technologies enhances operations related to life cycle design, green manufacturing, recycling, and remanufacturing, which in turn improves the environmental and economic performance of enterprises, has already addressed the impact of IoT on mechanisms for resource reuse, waste reduction, and business sustainability. The authors demonstrated that IoT contributes to more efficient management of resource flows, increases transparency, and supports the implementation of sustainable production systems. Further study is needed to quantify the economic efficiency of digital and IoT solutions, the long-term consequences of their implementation, the impact on structural changes and behaviour of market participants, issues of cybersecurity, standardisation, regulatory support, and factors that determine the readiness of organisations for digital transformation. The purpose of this study was to identify the key economic consequences of the implementation of IoT technologies and assess their impact on the efficiency, costs, and structure of modern business processes.

Materials and Methods

The study was theoretical in nature and was based on a targeted study of scientific literature, technical materials and analytical sources describing the architecture, economic characteristics and systemic effects of the implementation of the IoT in various sectors of the economy. To form the source sample, the criteria of relevance (2018-2025), scientific verifiability, availability of technical descriptions and economic parameters of IoT solutions were applied. The analysis included scientific articles, technical reports, corporate cases, and statistical reviews, and quantitative indicators were used as illustrative material for the analytical interpretation of the qualitative characteristics of technologies. The conceptual principles of the functioning of IoT in the digital economy were determined through the analytical interpretation of the scientific works of D. Tsipianitis *et al.* (2025) and K. Do *et al.* (2025), which made it possible to reconstruct the logic of building sensor networks, digital platforms, data flows and algorithmic modules, as well as to clarify the role of IoT as a structural element of economic digitalisation. The classification of IoT solutions was examined using the materials of A1 Digital (2025) through a structural-systematisation method, which enabled the identification and grouping of key categories of industrial, transport, energy, agricultural and urban systems, as well as the determination of their functional and architectural characteristics relevant for production and economic environments.

The economic characteristics of IoT projects were examined using the source N. Abebe *et al.* (2025) to identify the underlying patterns of cost formation, reconstruct the structure of integration and capital expenditures, and assess the contribution of cybersecurity requirements to total project costs, which enabled the development of a generalised cost model for IoT solutions. The efficiency and scaling effects of IoT were examined using the structural-analytical method based on the conceptual framework of A. Jarašūnienė *et al.* (2023), which made it possible to generalise how IoT influences productivity, operational performance and cost dynamics as device networks and data volumes expand. The life cycle of IoT projects was processed according to S. Rathore (2025) by functional-structural analysis, which made it possible to track the sequence of phases of development, integration, operation and technical support, as well as to determine at which stages the greatest economic effects occurred.

The level of automation achieved through IoT implementation was evaluated using a quantitative content-analysis approach based on the data presented by R. Daws (2025), which made it possible to identify the extent to which manual operations decrease and digital process integration expands after adopting IoT solutions. The indicators of productivity change were identified using a quantitative descriptive method applied to the data provided in S. Zoting & A. Shivarkar (2025). Environmental benefits, including energy efficiency, emission reduction, resource optimisation and the formation of circular models, were analysed according to A. Addas *et al.* (2024) using a qualitative analytical method.

The industrial sector was examined using a sector-focused content-analysis method based on the publications of A. Ramanenkava (2025) and Y. Sapra (2025), which enabled the identification of IoT-driven mechanisms of process automation, predictive maintenance, production environment control and defect reduction by analysing quantitative indicators of automation levels, downtime reduction, labour cost savings and quality improvement presented in these sources. Case materials Siemens MindSphere (Holmes, 2018) and Bosch (Ten years of Industry 4.0, n.d.) were used to reconstruct real practices of industrial use of IoT. Transport applications were studied based on a comparative analysis of corporate cases Unilever and DHL. This allowed to describe the principles of IoT routing, dynamic adjustment of logistics routes, monitoring of the technical condition of the fleet and monitoring driver behaviour using the examples of Walmart and Maersk (CodeXTeam, 2024). The use of materials Farnell (Amazon – a prime…, n.d.) made it possible to recreate the mechanisms of warehouse automation and digital inventory, while the sources Huawei (Tianjin port: Building…, n.d.) allowed to investigate the operation of sensor systems for monitoring port operations and managing cargo flows. These cases were selected because they represent well-documented and illustrative real-world implementations of IoT across different sectors, allowing for a comprehensive reconstruction of practical mechanisms of automation, monitoring and digitalised logistics. In the energy sector, a technical and organisational analysis was applied using the Department of Energy Security of the United Kingdom (2024) to describe the principles of operation of "smart meters" and algorithms for automated load management. The Siemens Energy case was analysed to examine how IoT-based remote monitoring and automated maintenance workflows are implemented in real industrial settings, enabling a deeper understanding of practical mechanisms of equipment diagnostics and operational optimisation (Siemens energy builds…, 2024). For the agricultural sector, an analytical-structural approach was used based on Indeema (How are drones…, 2025), which made it possible to describe sensor systems, IoT drones, precision farming algorithms and crop monitoring technologies. The analysis of urban infrastructure was carried out through a technical-functional method using materials of the AGC Lighting (2023), which provided a characterisation of adaptive light emitting diode algorithms and IoT integration with Heating, Ventilation, and Air Conditioning systems.

Macroeconomic analysis was carried out using the comparative analytical method based on O. Chang & J. Hsiao (2025), which made it possible to evaluate the contribution of digital technologies and IoT to GDP growth in Organisation for Economic Cooperation and Development (OECD) countries, the EU, the USA and China. These regions were selected because they represent the world's largest and most data-rich digital economies, allowing for reliable comparison of IoT-driven macroeconomic effects. Report of the OECD (2024) was used to analyse information and communication technologies (ICT) development dynamics through the ICT index, while report of the ITU (2025) served to assess how IoT penetration affects productivity indicators. Publications by H. Edquist *et al.* (2019) and H. Sloan (2024) were applied to reconstruct and quantify the macroeconomic mechanisms of IoT influence – specifically, to analyse how changes in productivity, cost structures, and resource efficiency translate into GDP and total factor productivity growth, based on empirical coefficients and macro-level estimations. The source by Yu. Shamrei (2024) was used to identify and compare the economic sectors that generate the highest aggregate contribution to GDP, which provided the basis for selecting priority industries for deeper sectoral analysis.

The functioning of technical and organisational barriers to IoT scaling was analysed using a regulatory-analytical method involving international standards IEEE 2413-2019 (2020), IEEE 802.15.4-2011 (2011), ISO/ IEC 27001:2022 (2022), and ISO/ IEC 30141:2024 (2024). Additional aspects of cybersecurity and interoperability were assessed based on the ISA/IEC 62443 series of standards (n.d.) and ETSI EN 303 645 V3.1.3 (2024). The identification of IoT implementation barriers was carried out using a regulatory-analytical method, based on the interpretation of empirical evidence and conceptual classifications presented in A. Alenizi & K. Al-Karawi (2023) and S. Madanian *et al.* (2024). This approach made it possible to systematise constraints into five key groups-technical, cybersecurity, human-resource, regulatory, and economic barriers-which served as the basis for further analysis of risks and their influence on IoT scalability. The prospects for sustainable IoT development were determined using a conceptual and analytical method through the interpretation of the potential of circular models, energy optimisation, Smart Grid and AI integration.

Results

Theoretical and economic foundations of the functioning of IoT technologies

The IoT is one of the key technological platforms of the digital economy, which provides integration of physical objects with digital systems using sensors, communication modules and data processing algorithms. In the most general definition, IoT is a network of interconnected devices capable of collecting, transmitting and analysing information without direct human intervention. This is a transition from the traditional model, where data was collected periodically and manually, to an ecosystem of continuous monitoring and automated decision-making. IoT provides an environment in which real-world objects – from household appliances to industrial equipment – become active participants in digital processes and form new economic mechanisms of interaction (Tsipianitis *et al.*, 2025).

The functioning of IoT is based on several basic principles: automated data collection using sensors, information transmission via communication networks, data processing in cloud or peripheral computing systems, generation of control signals and integration with other digital platforms. At the technological level, this means a combination of hardware components (sensors, controllers, gateways), communication protocols (Wi-Fi, Bluetooth, low-power wide-area network, 5G), software (analytical platforms, forecasting systems, visualisation modules) and cyber protection mechanisms. Such an architecture make it possible to form complex multi-level systems in which data is transformed into a key economic resource that determines the efficiency of processes, productivity and speed of decision-making (Do *et al.*, 2025).

The classification of IoT covers several dimensions. By scope of application, industrial IoT, household (smart homes), transport (intelligent transport systems), medical, agricultural, energy (Smart Grid) and urban (Smart City) are distinguished. Each category has specific technical requirements and economic mechanisms, but they are united by the ability to create added value through increased accuracy of operations, automation, resource savings and integration with other digital tools. From the point of view of architecture, there are edge, cloud and hybrid IoT systems, which differ in the way data is processed and the level of autonomy. At the same time, in the digital economy it is important to consider the classification by business models: subscription-based service solutions, data-driven models, "product as a service" and ecosystem platforms that connect manufacturers, consumers and developers (Al Digital, 2025).

The economic characteristics of IoT projects are formed at the intersection of three key dimensions: cost structure, efficiency and scalability parameters, as well as the features of the solution life cycle. Unlike traditional IT projects, where the main emphasis is on software and licenses, in the case of IoT, a significant share of costs is made up of physical devices (sensors, controllers, and gateways), network components, integration with existing systems and cyber protection. Initial investments include the purchase of equipment, deployment of network infrastructure, configuration of a platform for data collection and analytics, integration with business processes, as well as personnel training costs. Subsequent operating costs include maintenance, firmware updates, security support, data storage and processing in cloud or hybrid environments. As a result, the cost structure of an IoT project combines a significant amount of capital expenditure at the start with a gradual increase in operating expenses during operation, which requires the use of valuation models based on total cost of ownership and taking into account the full life cycle of the solution (Abebe *et al.*, 2025).

The assessment of the effectiveness of IoT projects is based on a combination of financial and non-financial indicators. Key economic parameters include reduced operating costs, reduced equipment downtime, increased labour productivity, reduced resource losses, increased revenue from new services, and improved customer service. At the enterprise level, the effects of IoT implementation are manifested in more accurate planning, predictive maintenance, logistics automation, energy-efficient management, and reduced risk of accidents or shortages. For quantitative assessment, return on investment, net present value, internal rate of return, as well as specialised metrics related to productivity and resource savings are used. An important aspect is scalability: as the number of connected devices and the volume of data expand, the average cost per device and unit of data tends to decrease, while the overall economic effect increases due to scale and network effects. At the same time, scaling requires a reliable network infrastructure, the ability of platforms to process large amounts of data in real time, and the availability of standards that ensure the interoperability of devices and systems (Jarašūnienė *et al.*, 2023). As shown in Figure 1, the structure of the economic characteristics of an IoT project is formed on the basis of cost, efficiency, and life cycle parameters that determine the sustainability of the solution in the long term.

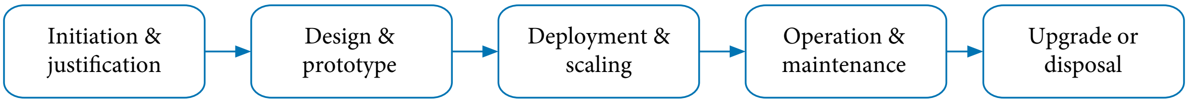

Figure 1. IoT project life cycle
Source: compiled by authors based on S. Rathore (2025)

The life cycle of IoT solutions has its own characteristics compared to classic IT projects. At the initiation stage, goals are formulated, economic expectations are determined, architectural approaches and deployment models (on premise, cloud, hybrid) are selected. This is followed by design and pilot implementation, where technical viability and basic economic effects are verified. At the large-scale deployment stage, the IoT system is integrated with enterprise resource planning, customer relationship management and other corporate platforms, a stable data flow is formed for analytics and decision-making. In the operation phase, update management, security, and maintenance of sensor and network performance become key; it is at this stage that the main part of the economic effect is gradually realised due to cumulative cost savings and increased productivity. The final stage includes modernisation or replacement of outdated devices, migration to new protocols and platforms, as well as disposal of equipment taking into account environmental requirements.

The economic characteristics of an IoT project are therefore determined not only by the initial costs, but also by how effectively the solution is integrated into the digital infrastructure of the enterprise, how quickly it scales and what long-term benefits it generates at all stages of the life cycle. That is why, in order to justify the feasibility of implementing IoT, it is necessary to combine cost analysis, efficiency assessment and life cycle modelling, taking into account both direct financial results and strategic effects related to innovation and competitiveness. After implementing IoT technologies, enterprises demonstrate an increase in the level of automation, as IoT eliminates a significant part of manual actions and allows them to be replaced by digital processes. On average, after IoT integration, about 57.5% of operational processes are automated, although in some companies this figure reaches 75% already during the first year of use (Daws, 2025). The reduction in manual operations is generally from 40% to 60%, which is due to the transition to remote monitoring, automatic control and predictive maintenance (Kurduban, 2024). The use of IoT in combination with AI algorithms further enhances these effects: for example, predictive maintenance has an implementation rate of 71%, IT automation – 53%, which allows enterprises to reduce the number of manual interventions and achieve an increase in overall efficiency by 20-30%. The real effect of automation is also manifested in cost savings, in particular in reducing labour costs by about 25%.

One of the key areas of productivity improvement is downtime reduction. Due to IoT-supported equipment condition monitoring, enterprises reduce unplanned downtime by an average of 25-35%. This is achieved by early detection of anomalies, automatic call of technical teams and optimisation of the maintenance schedule (Oxmaint, 2025). Predictive maintenance makes it possible to reduce the response time to malfunctions by 70%, reduce repair costs by 50% and extend the service life of equipment by approximately 20%. As a result, industrial enterprises record up to 40% reduction in downtime and 20-30% increase in productivity due to stable equipment operation and more accurate planning of production processes (Zoting & Shivarkar, 2025).

IoT is also a central element in the development of analytics, since the amount of data generated by devices ranges from tens of terabytes to several petabytes per year within one enterprise. The use of real-time analytics provides an average increase in productivity by 10-30%, a reduction in scrap rates by 18%, an increase in production output by 10-15%, and optimisation of logistics and warehouse operations (ARO, 2023). Due to this, IoT creates conditions for the formation of data-driven decision-making models that increase the adaptability of enterprises and accelerate innovation processes (Tely AI Team, 2025).

The spread of IoT is changing the logic of business functioning and stimulating the development of new business models. In the EU and the United States, from 20% to 30% of companies use subscription models (subscription IoT), and the global service market is estimated at USD 293.4 billion in 2025 with a forecast growth to USD 1.86 trillion by 2035. The development of models such as "product-as-a-service" enhances the economic flexibility of enterprises and ensures long-term revenue growth, in particular due to the high profitability of data-driven services (Future Market Insights, 2025a).

In the context of global trends of sustainable development, IoT provides tangible environmental benefits. Optimisation of transport routes based on IoT reduces CO_2 emissions by 10-20%, while the use of optimisation algorithms, including Hybrid Genetic Algorithms, allows for a reduction of up to 23% (Bar, 2025). Smart energy technologies reduce energy consumption of enterprises, reduce losses and increase the efficiency of resource use. One of the most dynamic areas is smart waste management: the global market for such solutions is estimated at USD 3.17 billion in 2025 with a forecast of growth to USD 14 billion by 2035 (Future Market Insights, 2025b). The use of bin fullness sensors and automated sorting can reduce waste volumes by 20-45%, improve collection logistics efficiency by 32%, and increase waste recycling rates by 25-45% (Addas *et al*., 2024). These results confirm that IoT is becoming not only a tool for economic transformation, but also a key technology for shaping energy-efficient, low-carbon, and circular development models.

In summary, the economic properties of IoT implementation form a complex multiplier effect, which is manifested simultaneously at the level of costs, productivity, management decisions and environmental performance. The combination of automation, predictive analytics and scalable digital infrastructure creates a new model of enterprise functioning, in which data becomes the basic resource for creating value. Reducing manual operations, reducing downtime, increasing the accuracy of processes and flexibility of business models provide enterprises with both short-term savings and long-term strategic advantages, in particular, resistance to market fluctuations, faster adaptation to technological changes and the formation of new sources of income. Thus, IoT is transformed from a separate technological tool into a system-forming platform for economic development, which changes the logic of production, management and competition in the digital economy.

Economic impact of implementing IoT projects at the micro and macro levels

The IoT is demonstrating significantly different but systematically positive economic returns in key sectors – industry, logistics, energy, agro-industrial complex, urban infrastructure and healthcare. The impact of IoT is manifested through process automation, predictive maintenance, resource optimisation, defect reduction, cost reduction, improved asset management, reduced transaction time and increased decision-making accuracy. At the same time, specific economic effects are observed in each sector, determined by the nature of operations, level of digital maturity, scale of equipment and density of data flows. In industry, IoT is one of the main catalysts for the transition to "smart factories". One of the key effects is automation: enterprises that have implemented IoT automate an average of 57.5% of operational processes, and some – up to 75% within the first year, which leads to a reduction in labour costs by 25% and an increase in productivity by 20-30% (Ramanenkava, 2025). The reduction in manual operations reaches 40-60%, and unplanned downtime is reduced by 25-50% due to predictive maintenance, which is also rarely possible without IoT-based equipment monitoring. Companies that have integrated IoT into quality and control of production environments record a reduction in product defects by 25-50%, and in some cases up to 70%, while the use of robotics connected to IoT sensors provides flexible reconfiguration of production scenarios, increases accuracy and reduces losses (Sapra, 2025).

Examples of corporate cases confirm the scale of the effects. Siemens MindSphere provides an improvement in overall equipment effectiveness from a baseline of 40-50% to 60-85%, an increase in production up to 25%, and a reduction in defects due to the closure of the quality management loop (Holmes, 2018). Bosch demonstrates an increase in production efficiency by 25-30%, an increase in equipment productivity by 15-20%. (Ten years of Industry 4.0, n.d.). Thus, for the industrial sector, IoT is a mechanism for generating economies of scale, which manifests itself simultaneously at the capital expenditure and operating expenses levels.

In transport and logistics, IoT also has a significant economic impact associated with cost reduction, route optimisation, and increased delivery speed. IoT routing reduces transportation costs by an average of 10-25%, while dynamic traffic optimisation reduces fuel consumption by 10-15% and reduces repair costs caused by accidents and wear and tear by monitoring driver behaviour and fleet condition. Unilever demonstrates a 25% reduction in delivery times through the use of IoT and AI route optimisers, DHL – 20% reduction in delays, while Walmart and Maersk – from 10% to 25%, depending on transportation models (CodeXTeam, 2024). Amazon Web Services IoT provides full automation of order processing, inventory management, and delivery monitoring: order reprocessing is reduced, picking is accelerated, and inventory accuracy is significantly improved by integrating sensors into warehouse operations (Amazon – a prime…, n.d.). Huawei's IoT connectivity enables real-time equipment and cargo monitoring, rapid fault detection, and automatic adjustment of port operations, reducing ship downtime by 7% and shortening operation planning time from 24 hours to 10 minutes (Tianjin port: Building…, n.d.).

In the energy sector, IoT provides a significant reduction in energy consumption and increases the efficiency of network management. The use of "smart meters" allows households to reduce electricity consumption by 2.5-3.5%, and in some cases up to 3.4% in the first year, with the trend continuing in subsequent years. Automated Smart Grid management reduces losses in networks by 15-25%, reduces peak loads by 10-25%, improves reliability and reduces the duration of emergency shutdowns (Department of Energy Security of the United Kingdom, 2024). Siemens Energy demonstrates a reduction in manual data collection time by 50%, maintenance costs by 25%, and equipment availability increases by up to 15% (Siemens energy builds…, 2024).

The agro-industrial complex receives significant economic benefits through the use of IoT drones, sensor systems and analytics. Targeted application of agrochemicals using IoT drones reduces pesticide and fertiliser use by 30-45%, while crop yields increase by 15-30% through point-to-point monitoring of crop conditions. Water consumption is reduced by up to 90% in precision irrigation systems, and crop forecast accuracy increases to 85-90%, providing better stability of the production cycle and minimising financial risks (How are drones…, 2025)

Urban infrastructure benefits from IoT through energy optimisation, reduced data processing time, and improved quality of municipal services. IoT lighting reduces electricity consumption by 30-75%, depending on the level of light emitting diode integration and adaptation algorithms, while integration with Heating, Ventilation, and Air Conditioning provides additional 20-40% savings (AGC Lighting, 2023). Edge data processing speeds up city services by 70-71%, optimising response to critical events. In waste management, IoT provides fuel savings of 25-40%, reduces the number of routes by 25-30%, reduces waste going to landfills by 10-30%, and increases the accuracy of sensor monitoring to 95% (Pioli *et al*., 2024). In healthcare, IoT is helping to radically improve diagnostic accuracy, reduce costs, and improve the quality of care for chronic patients. The interaction of wearable medical devices with hospital systems provides monitoring accuracy of 87-95%, and the sensitivity of condition detection algorithms is up to 94-95%. Implementation of Remote Patient Monitoring reduces readmissions by up to 38%, saving about USD 6,500 per patient per year.

As a result, IoT creates a comprehensive economic effect in every sector of the economy, forming a synergy of technological automation, resource optimisation and intelligent management. Industry receives the greatest aggregate economic growth through automation and reduced downtime; logistics – due to a significant reduction in costs and accelerated deliveries; energy – through network optimisation and reduction of peak loads; the agricultural sector – through the accuracy of forecasts and resource savings; cities – through reduced energy consumption and improved operational efficiency; healthcare – through increased monitoring accuracy, early diagnosis and reduced hospitalisations. Thus, IoT is not only a tool for technological modernisation, but also one of the key drivers of increased productivity, innovative dynamics and economic sustainability at the national and global levels.

Digital technologies and IoT significantly contribute to GDP growth across countries and regions such as OECD members, the EU, the USA, and China, although the extent and nature of this impact vary. In OECD countries, the ICT sector has grown approximately three times faster than the overall economy between 2013 and 2023. During this period, the ICT sector demonstrated an average annual growth rate of 6.3%, which further increased to 7.6% in 2023. This sector remains a key driver of global economic expansion; however, the adoption of advanced technologies such as AI and IoT in non-ICT industries is still limited. This indicates significant untapped potential for accelerating economic performance through broader technological diffusion. At the same time, investments in AI continue to rise, strengthening the economic relevance of digital technologies in OECD (2024) economies. In the United States, GDP growth in early 2025 was strongly driven by investments in AI data centres and IT infrastructure, confirming the central role of digital technologies in maintaining economic momentum. The North American IoT market accounts for a substantial share of global spending on IoT devices and solutions, underscoring its contribution to productivity increases and sector-specific efficiencies (Chang & Hsiao, 2025).

Globally, IoT applications are estimated to generate trillions of dollars in annual economic value, with projections reaching up to USD 11 trillion by 2030. Industrial IoT alone could add approximately USD 14.2 trillion by 2030, particularly benefiting manufacturing and healthcare by boosting operational efficiency and introducing new value-creation mechanisms. Although the provided sources contain limited specific data for China, the country's well-documented large-scale investments in IoT, AI, and digital infrastructure indicate that these technologies substantially support national GDP growth by enhancing industrial productivity, advancing smart city programmes, and expanding the digital economy in line with global trends (Shamrei, 2024). Overall, digital technologies and IoT contribute significantly to GDP dynamics by accelerating ICT sector development, enabling AI-supported efficiency improvements, and transforming industries through connected systems. OECD countries and the USA benefit from both direct ICT sector expansion and the broader potential associated with increased technology diffusion, while the global economy is positioned to experience continued growth as IoT transforms production and service ecosystems. Connectivity, as a foundational component of IoT, demonstrates a measurable macroeconomic effect. A 10% increase in fixed or mobile broadband penetration is associated with about a 1.5-1.6% rise in GDP per capita. This effect tends to be stronger in advanced economies due to larger digitalisation scale effects. In the United States, the digital economy represents roughly 18% of GDP as of 2024, contributing to rapid job creation, innovation, and productivity growth. Overall, the global digital economy is growing approximately 2.5 times faster than global GDP, with IoT functioning as a central mechanism for transitioning toward more connected and data-driven economic models (ITU, 2025).

Changes in productivity, efficiency, and cost structures resulting from IoT implementation are reflected in macroeconomic indicators such as GDP growth and total factor productivity. A 10-percentage-point increase in IoT connections per capita correlates with approximately a 0.23-percentage-point increase in total factor productivity growth, which directly raises economic output. Recent assessments estimate that IoT contributes about USD 849 billion annually to global GDP through productivity gains (Edquist *et al*., 2019). IoT improves productivity by optimising resources, enabling predictive maintenance, streamlining workflows, and reducing energy consumption-particularly in manufacturing, healthcare, and urban infrastructure. These efficiency gains lower operating costs, reduce capital intensity, and encourage innovation, collectively increasing GDP and strengthening economic competitiveness. A 10% rise in machine-to-machine interactions (an indicator of IoT growth) could increase US GDP by USD 2.3 trillion over the next 30 years. Notably, IoT's indirect impacts – productivity spillovers and cross-sector complementarities – further amplify these macroeconomic benefits (Sloan, 2024).

Sectors generating the largest contributions to GDP through IoT include manufacturing, transport, healthcare, energy, and services. Manufacturing remains the leading contributor, with industrial IoT offering economic potential of USD 1.2-3.7 trillion by 2025 through improved monitoring, predictive maintenance, and supply chain optimisation. The transport and automotive sectors also gain substantially due to IoT-enabled fleet management and connected vehicle technologies, with the automotive IoT market expected to exceed USD 500 billion by 2025. Healthcare represents another major contributor, with the IoT healthcare market projected to reach USD 534 billion by 2025 as connected devices improve diagnostics and reduce costs. In the energy sector, smart grids and IoT-based monitoring significantly enhance energy efficiency and resource management, generating considerable economic value, including estimated electricity savings of 1.8 petawatt-hour in the US by 2030. Service industries, including retail and smart cities, also experience substantial benefits from IoT applications that streamline operations and improve infrastructure management (Shamrei, 2024). In summary, the largest GDP contributions from IoT come from manufacturing and transport, followed by healthcare and energy, while service sectors add value through innovation and infrastructure improvements. IoT acts as a powerful driver of productivity, investment, and efficiency gains across economies, strongly influencing GDP and national competitiveness at the macroeconomic level.

Barriers, risks and prospects for scaling IoT in economic systems

The implementation of IoT systems is becoming crucial for the transformation of enterprises and sectors of the economy, but the scaling of such solutions is accompanied by a number of technical, organisational, institutional and economic barriers. In practice, IoT projects are complicated by the lack of common standards, low compatibility of equipment, high requirements for cyber security, a shortage of qualified specialists and the need to adapt internal business processes. At the same time, state regulation and international standards form the framework conditions for the functioning of IoT, and the economic risks of integration stimulate the development of models for minimising uncertainty. In the medium and long-term development horizon, IoT becomes a key basis for circularity, energy optimisation and strategic growth of the economy.

Technical and organisational barriers are the most difficult, as they are manifested directly in operational activities. One of the central challenges is interoperability: sensor and platform manufacturers often use different communication protocols, which complicates system integration, creates data duplication and requires additional adapters or gateways. The low level of standardisation slows down the scaling of solutions and increases the dependence of businesses on individual vendors. In parallel, the importance of cybersecurity is growing: the increase in the number of connected devices opens up a wider "attack field", and therefore requires advanced methods of encryption, authentication and network segmentation. Many companies also face staffing constraints, as IoT integration requires specialists in related competencies – network engineering, cyber security, big data analytics, development and operations. In addition, organisational barriers are manifested in the need to reorient internal processes, rebuild asset management systems and train personnel, which increases the time and financial cost of the transition to IoT. Integration of IoT into business processes is always accompanied by economic risks. Investment risks are formed due to the high cost of equipment, the need to modernise network infrastructure, costs for cyber security and operational updates. Additionally, there are security risks associated with possible cyberattacks, interference with production equipment or unauthorised access to critical data. The risk of not achieving economic effect is due to the fact that the effectiveness of IoT depends on the quality of sensors, algorithms, integration with enterprise resource planning and customer relationship management systems, staff readiness and digital culture of the enterprise. In practice, various models of risk minimisation are used in implementation: phased scaling of minimum viable product (solutions, testing on local sites, cloud models for reducing capital costs, cybersecurity frameworks and hybrid architecture with the distribution of critical functions between edge and cloud (Gerodimos *et al*., 2023).

The technical barriers to IoT implementation are largely determined by the lack of interoperability and the lack of a unified technical framework, which makes it difficult to scale systems at the enterprise and industry level. International standards play a key role in overcoming these limitations. In particular, ISO/IEC 30141:2024 (2024), developed by ISO and the IEC, forms a universal reference architecture for IoT, which defines the levels of device interaction, data exchange requirements and logic of functional modules. Its compliance ensures the coordinated creation of IoT platforms and interoperability between manufacturers. An important component of technical interoperability are wireless communication standards, in particular the IEEE 802.15.4-2011 (2011), developed by IEEE. It defines the basic parameters of data transmission in low-power networks, on which Zigbee, Thread and Pv6 over Low power Wireless Personal Area Networks (6LoWPAN) technologies are based, which form the basis for sensor networks of smart homes, meters and industrial sensors. For broader system coordination, IEEE 2413-2019 (2019) is also used, which describes a conceptual model of interaction between various IoT solutions and platforms, ensuring interoperability and data consistency.

The problem of security standardisation should be noted separately, since most IoT projects operate in conditions of large-scale data processing, constant network connectivity and high vulnerability to cyberattacks. The key standard in this direction is ISO/IEC 27001:2022 (2022), which defines requirements for information security management systems, including risk assessment, encryption, access control and verification of environmental reliability. In the industrial sector, the basis of cyber security is formed by ISA/IEC 62443 series of standards (n.d.) (Industrial Communication Networks – IT Security for Industrial Automation Systems), which sets requirements for network segmentation, protection of controllers, Supervisory Control and Data Acquisition (SCADA) and other automation systems.

In the consumer sector, the basic standard is the ETSI EN 303 645 V3.1.3 (2024), which prohibits the use of standard passwords, regulates firmware updates, encryption and protection of personal data. Institutional barriers are also associated with the lack of harmonised regulatory regimes. International standards provide the basis, but the implementation of IoT requires state coordination mechanisms, adaptation of regulatory frameworks and establishment of requirements for security and interoperability. National regulatory frameworks should be based on international standards to ensure the rapid implementation of innovations, and include institutional incentives for infrastructure modernisation. In this regard, the technical, organisational and regulatory aspects of IoT implementation are interconnected. International standards – ISO/IEC 30141, ISO/IEC 27001, IEC 62443, IEEE 802.15.4, IEEE P2413 and ETSI EN 303 645 V3.1.3 (2024) – form the basic framework for interoperability, security, architectural consistency and compliance of technological systems, ensuring the scalability of IoT at the level of industry, energy, agriculture and urban infrastructure. The main barriers and risks are highlighted in Table 1.

Table 1. Key barriers and risks of IoT system implementation

Barrier group	Nature of the barrier	Impact on implementation	Typical consequences
Technical	Low interoperability, lack of standards	Complicated integration	Data duplication, increased project costs
Cybersecurity	Attack risks, weak network segmentation	High protection requirements	Process shutdowns, data leaks
Human resources	Shortage of IoT/ development and operations/security specialists	Slower scaling	Rising project costs
Regulatory	Instability of requirements, bureaucracy	Slower implementation	Certification delays
Economic	High capital expenditure/operating expenses, uncertain return on investment	Low profitability at early stages	Risk of not achieving the expected effect

Source: compiled by authors based on A. Alenizi & K. Al-Karawi (2023), S. Madanian *et al.* (2024)

The prospects for sustainable development of IoT are determined by the fact that this technology becomes the core of the circular economy, energy optimisation and low-carbon transformation. The circular economy involves closed material cycles, resource reuse, waste reduction and increased logistics efficiency. IoT provides detailed monitoring of the life cycle of products, control of storage conditions, traceability and sensor-based control of equipment wear, which reduces the resource intensity of production. In the energy sector, IoT provides the ability to integrate distributed generation, optimise loads, flexible network management and transition to intelligent Smart Grids. Emissions monitoring systems, energy consumption analysis and microgeneration plant management contribute to the low-carbon transition and environmental sustainability. At the micro level, key strategic trajectories are increasing the operational efficiency of enterprises, automation of logistics, optimisation of production processes, real-time asset management and implementation of predictive maintenance models. Enterprises are moving to digital twins, robotic processes, and data flow analytics, and comprehensive automation, which can reduce costs, improves product quality, and reduces waste. In urban infrastructure, IoT opens up prospects for intelligent mobility, energy-efficient construction, automated traffic management, pollution reduction, and utility optimisation (Rejeb *et al.*, 2022).

At the macro level, IoT is becoming one of the key drivers of national competitiveness. Countries with a high rate of digitalisation, in particular China, European Union countries, Japan, the Republic of Korea, Taiwan, China, and the United Kingdom, demonstrate accelerated GDP growth, active development of high-tech exports, and increased investment in digital infrastructure. IoT scaling contributes to productivity growth, increases the efficiency of economic sectors, enhances innovation capabilities, and creates conditions for the expansion of digital markets. The combination of institutional support, unified standards, and strategic investments in digital ecosystems provides countries with the ability to make technological breakthroughs and strengthen economic resilience (World Bank Group, 2024).

As a result, the barriers to IoT implementation are multidimensional and cover technical, organisational, institutional, and economic dimensions. However, a systematic approach to overcoming them, combining standards, cyber security, institutional incentives, and strategic planning, provides the opportunity for large-scale integration of IoT into all levels of the economy. Sustainable development, digital transformation, and energy optimisation are shaping new conditions in which IoT is not just a technology, but also a fundamental infrastructure for economic and social progress.

Discussion

The rapid spread of digital solutions has gradually changed economic dynamics, affecting both the structure of production and resource management mechanisms. Various scientific approaches to digitalisation shared a common theme: digital technologies have become the foundation of economic modernisation. This was clearly evident in the results of this study and in the conclusions of R. Li & J. Zheng (2025), where the digital economy was assessed as a factor in increasing productivity and transitioning to higher quality production. In both works, digital solutions enhanced innovation and rationalised the use of resources, although the emphasis differed. R. Li & J. Zheng (2025) focused on the manufacturing sector and identified the role of digital literacy and manufacturing agglomeration as factors that modified the strength of the effect, while in this study, the effectiveness of IoT was traced in an inter-sectoral context without modelling such moderators.

The differences became more pronounced when compared to the study by K. Bai *et al.* (2024). In K. Bai *et al.* (2024) the digital economy emerged as a tool not only for modernisation, but also for increasing inclusiveness and equalising socio-economic opportunities, while in this study, the sectoral and applied dimensions dominated – analysis of automation, reduction of downtime, resource savings, and productivity gains. K. Bai *et al.* focused on institutional barriers and digital inequality, while here the main constraints were technical and organisational factors of IoT integration. Despite this, both studies demonstrated that digital solutions shaped a renewed model of economic efficiency. The contrast was even more pronounced when compared to Y. Liu *et al.* (2024). Y. Liu *et al.* viewed digitalisation through the prism of socioeconomic equality-income growth, reduced inequality, and expanded opportunities for rural areas. In this study, digitalisation had a different research perspective: IoT was evaluated in terms of its impact on productivity, cost dynamics, and the overall efficiency of economic processes, without analysing socio-distributional outcomes. Despite this, both studies confirmed that digital technologies triggered mechanisms of structural change.

A similar correlation was observed in comparison with J. Ding (2024). J. Ding analysed the digital economy in interaction with new infrastructure – 5G, AI, transport and energy networks –, which created a large-scale economic multiplier effect. This study focused on sectoral IoT mechanisms, which allowed for a detailed analysis of specific technical and economic benefits, but did not cover the infrastructural and social dimensions characteristic of J. Ding's approach. Despite different horizons of analysis, both works saw digitalisation as the basis for productivity and innovation. A comparison with X. Wang *et al.* (2024) showed that digital technologies in all the studies analysed formed the basis for economic renewal, but X. Wang *et al.* emphasised socio-economic transformations – changes in employment, the role of human capital, and institutional prerequisites for development. Here, the analysis was based on an assessment of sectoral technical results, which distinguished the study in terms of its analytical horizon, but not in terms of the overall logic of its conclusions.

A comparison of this study with the results of X. Wang *et al.* (2024) showed that, regardless of the scale of the analysis, digital technologies consistently demonstrated the ability to enhance productivity and reduce transaction and operating costs. However, further consideration revealed significant differences in the interpretation of these processes. In X. Wang *et al.* (2024) digitalisation was part of a broader socio-economic transformation that included changes in the labour market, human capital development, and institutional prerequisites for structural reforms. Here, digital solutions were evaluated in more applied context-through real changes in operational processes, automation, reduced downtime, and total factor productivity growth in specific sectors. The focus on social effects, characteristic of X. Wang *et al.* (2024) was not central to this study. This division between the macro and applied levels was also clearly evident in comparison with A.F. Kineber (2024). In A.F. Kineber, the digital economy was viewed primarily as a strategic resource for national development, influencing investment flows, market structure, and the transformation of business models. In contrast, in this study, digitalisation emerged through the direct technical and economic effects of IoT, which manifested themselves in cost reduction, resource optimisation, acceleration of production cycles, and stable productivity growth at the enterprise and sector levels. Both approaches emphasised the modernisation potential of digital technologies, but differed in the scope of their analytical perspective.

The contrast in research perspectives became even more noticeable when compared with C. Zhang *et al.* (2024). C. Zhang *et al.* analysed digitalisation as a factor in regional equalisation, sustainable development, and environmental efficiency. The researchers integrated the digital economy into the broader context of spatial disparities and institutional differences, emphasising the ability of digital technologies to reduce inequality and stimulate innovative activity in cities. In the same study, digital infrastructure manifested itself through other mechanisms – by increasing the accuracy of management decisions, optimising resource flows, and reducing production losses in sectoral systems. The environmental and regional impacts of digitalisation were not included in the analysis. The generalisation of the comparative results showed that digital technologies in all considered approaches formed the basis of economic renewal, although the interpretation of this process differed depending on the research optics. In some works, digitalisation appeared as an element of large-scale socio-economic transformations, while in this study, applied analysis of sectoral effects of IoT – automation, cost optimisation and productivity growth – dominated. Despite differences in focus, all comparisons confirmed that digital infrastructure remained a key factor in long-term growth, innovation and sustainability of economic systems.

Conclusions

The research systematised the key theoretical and economic principles of the IoT as a foundational technology of the digital economy. Analysis of scientific sources showed that IoT creates a new architecture of economic processes by integrating sensor networks, real-time algorithms, communication platforms and analytical modules into a unified digital environment. The classification of IoT solutions demonstrated their wide applicability, while the evaluation of economic characteristics revealed that the cost structure is shaped mainly by capital investments, integration and cybersecurity. The analysis of the IoT life cycle confirmed that the strongest economic effects emerge during the operational stage due to resource savings, predictive maintenance and automated management.

The sectoral analysis showed that IoT has a multidimensional impact on economic efficiency. In industry, automation after IoT implementation ensures about 57.5% digitalisation of operations, reduces manual actions by 40-60% and lowers labour costs by nearly 25%. Predictive maintenance decreases unplanned downtime by 25-35%, and sometimes up to 40%, increasing productivity by 20-30%. In logistics, IoT-based routing reduces transportation costs by 10-25% and fuel consumption by 10-15%. In the energy sector, smart meters reduce consumption by 2.5-3.5%, while Smart Grid decreases network losses by 15-25%. In agriculture, IoT drones lower agrochemical use by 30-45%, cut water consumption by up to 90% and increase yields by 15-30%. In urban infrastructure, IoT lighting reduces energy consumption by 30-75%, and heating, ventilation, and air conditioning integration adds 20-40% savings, confirming the decisive role of IoT in transforming operational models.

At the macroeconomic level, the study found that the digital economy in OECD countries grew 2.5 times faster than GDP, while a 10-pp increase in IoT connections raises total factor productivity by 0.23 p.p. and generates a global effect of about USD 849 billion annually. The largest macroeconomic contribution comes from industry, transport, healthcare and energy, while services also benefit from automation and new digital models.

The study additionally showed that IoT scaling is limited by interoperability issues, insufficient standardisation, cybersecurity risks and shortages of qualified personnel. Nevertheless, long-term prospects are linked to circular economy models, energy system optimisation, Smart Grid expansion, digital platforms and deeper integration of AI. A limitation of the study is that it relied on available aggregated statistical data and secondary sources, which limited the depth of comparative analysis between individual industries and countries. Further research could be aimed at developing industry-specific models for assessing the effectiveness of IoT and deepening the analysis of long-term economic effects across countries.

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Економічні аспекти проектів на основі Інтернету речей

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Анотація. Метою цього дослідження було вивчити, як впровадження технологій Інтернету речей (IoT) впливає на економічні показники, оцінивши їхній вплив на ефективність, зниження витрат та трансформацію бізнес-процесів. Методологія базувалася на теоретичному аналізі наукових джерел, контент-аналізі технічних описів, порівняльній оцінці корпоративних кейсів та галузевих аналітичних підходах. Результати показали, що IoT забезпечує істотне та стабільне підвищення ефективності в усіх секторах. У промисловості цифровізація досягає 57,5 %, ручні дії зменшуються на 40-60 %, а витрати на робочу силу знижуються приблизно на 25 %. Прогнозне технічне обслуговування знижує незаплановані простої на 25-35 % і підвищує продуктивність на 20-30 %. У логістиці інтелектуальне маршрутизування зменшує транспортні витрати на 10-25% і час доставки на 20-25 %. У сільському господарстві дрони та датчики скорочують використання агрохімікатів на 30-45 % і споживання води до 90 %, а врожайність збільшується на 15-30 %. В енергетичному секторі інтелектуальні лічильники зменшують споживання електроенергії на 2,5-3,5 %, а системи Smart Grid зменшують втрати в мережі на 15-25 %. На макрорівні цифрова економіка в країнах Організації економічного співробітництва та розвитку зростала в 2,5 рази швидше, ніж валовий внутрішній продукт, а 10-відсоткове збільшення підключень до Інтернету речей підвищило загальну продуктивність факторів виробництва на 0,23 відсоткових пункти. Дослідження також виявило перешкоди для впровадження, зокрема обмежену сумісність, відсутність стандартів, ризики безпеки, нестачу фахівців, нестабільне регулювання та високі інвестиційні й операційні витрати з невизначеною віддачою. Результати можуть бути застосовані підприємствами та державними установами для підвищення ефективності та оптимізації використання ресурсів

Ключові слова: цифрова інфраструктура; сенсорні мережі; дані в режимі реального часу; операційна ефективність; інвестиції; кібербезпека