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IoT's Economic Impacts on Smart Cities

Emre Deniz *,[1]
*Department of Computer Engineering, Hitit University, 19030, Corum, Turkiye.

ABSTRACT This article comprehensively examines the economic impacts of the Internet of Things (IoT) on smart cities. Smart cities aim to enhance sustainability, efficiency, and quality of life through the integration of IoT technologies. The economic benefits of IoT in various domains, such as infrastructure management, energy conservation, transportation optimization, and the improvement of public services, are elaborated. Furthermore, potential costs and challenges, including high initial investments, data security concerns, and workforce transformation, are discussed. Supported by a literature review and current case analyses, the article presents findings that highlight IoT's contributions to the economic structure of smart cities and the barriers encountered. In conclusion, it emphasizes that IoT technologies have the potential to stimulate economic growth in smart cities through proper strategic planning and policy support.

KEYWORDS
Internet of things
Smart cities
Sustainability

INTRODUCTION

With rapidly increasing urbanization rates, the global urban population, which currently stands at approximately 55 billion, is projected to rise to 68 billion by 2050 Nations (2018). This accelerated urbanization process brings significant challenges in areas such as infrastructure, energy, transportation, healthcare, and public services. Traditional urban management approaches struggle to meet these growing demands and fall short in terms of sustainability and efficiency (Neirotti *et al.* 2014). In this context, the concept of smart cities emerges as a solution to make cities more livable, sustainable, and economically efficient through the integration of technological innovations. At the core of smart cities lies the Internet of Things (IoT), which enables physical objects to communicate with each other and with central systems via the internet, facilitating data collection, analysis, and automation processes (Atzori *et al.* 2010). IoT technologies support the digital transformation of urban infrastructures, enabling more efficient resource management, reduced operational costs, and improved service quality (Gubbi *et al.* 2013).

The economic impacts of IoT in smart cities are multidimensional and complex. On the one hand, IoT technologies optimize resource utilization, promote energy savings, and enhance efficiency, thereby reducing costs (Porter and Heppelmann 2014). On the other hand, the establishment and maintenance of IoT infrastructure require high initial investments, incur additional costs related to data security and privacy, and drive transformations in the labor market (Zanella *et al.* 2014). A detailed examination of these economic impacts is crucial for ensuring the sustainability and economic success of smart cities.

The primary objective of this article is to analyze the economic impacts of IoT in smart cities comprehensively. To achieve this, the following research questions will be addressed:

- How do IoT technologies contribute to the economic efficiency of smart cities? Contributions to resource management and operational efficiency.
- What role does IoT play in creating new job opportunities and employment in smart cities? Emerging job sectors, employment opportunities, and labor force transformations.
- What are the costs and economic challenges associated with IoT integration? Initial investments, maintenance and upgrade expenses, data management costs.
- How are IoT's economic impacts observed in different smart city examples?

Research on IoT and smart cities reveals the broad impacts of these technologies on urban management. Batty *et al.* (2012) detailed how smart cities align with future urbanization trends and the role of IoT in this process. Atzori *et al.* (2010) explored the fundamental components of IoT and its potential benefits for smart cities. More recent studies have focused on the economic impacts of IoT, analyzing its contributions to sustainability and economic growth (Gubbi *et al.* 2013).

This article aims to fill gaps in the existing literature and provide a more comprehensive perspective on the economic impacts of IoT in smart cities. Specifically, it seeks to balance both the positive and negative economic effects and enhance its analysis through case studies of different smart cities. Moreover, this work aims to expand the limited research on the economic impacts of smart city projects in developing countries like Turkey. Figure 1 illustrates the diverse application areas of IoT, ranging from smart

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[1]emredeniz@hitit.edu.tr (**Corresponding author**)

cities to healthcare and beyond. This transformation creates new opportunities for both the public and private sectors while also introducing various economic impacts and challenges.

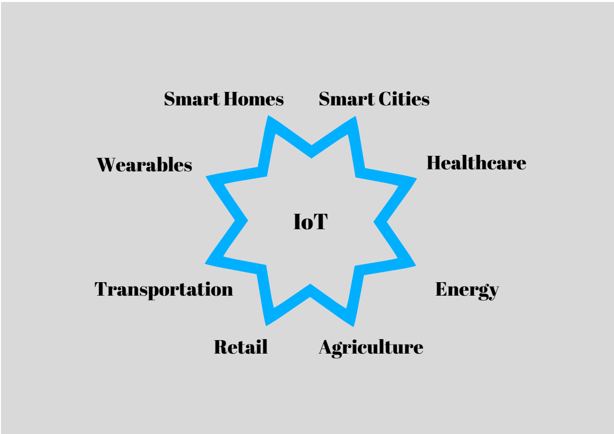

Figure 1 Applicaitons of IoT

This research offers valuable insights into the economic impacts of IoT in smart cities, providing city planners, policymakers, and the business community with essential knowledge. By addressing both the benefits and costs in a balanced manner, this study aims to enable more informed decision-making in the planning and implementation of smart city projects. Additionally, the analysis of different smart city examples contributes to identifying best practices and success factors. This facilitates the development of strategies and policies necessary to make smart cities sustainable and economically efficient.

MATERIALS AND METHODS

This section provides a detailed definition of the Internet of Things (IoT) and smart cities, followed by an examination of the relationship and interaction between these two concepts. This comprehensive review aims to better understand the role of IoT in smart cities and its economic implications.

Internet of Things

The Internet of Things (IoT) refers to a broad network of physical objects enabled by sensors, software, and other technologies to communicate with each other and central systems via the internet (Atzori *et al.* 2010). Core components of IoT include devices, connectivity infrastructure, data processing, and user interfaces (Gubbi *et al.* 2013). IoT is utilized across a wide spectrum of applications, from daily life to industrial environments, enhancing operational efficiency and enabling the emergence of new business models through its data collection and analysis capabilities (Madakam *et al.* 2015).

IoT operates through a system in which physical devices gather data via sensors, transmit it wirelessly to central servers, and analyze it to generate actionable insights (Zanella *et al.* 2014). This process enables real-time decision-making, automation, and process optimization. For example, smart thermostats optimize energy consumption, while smart meters monitor water and electricity usage to prevent resource waste (Ashton 2009).

These capabilities offer significant economic benefits not only to individual users but also to businesses and public institutions. The economic impacts of IoT manifest particularly in areas such as cost savings, efficiency improvements, new revenue models, and increased innovation capacity (Porter and Heppelmann 2014).

The Concept of Smart Cities Smart cities integrate information and communication technologies (ICT) to make urban management and services more efficient, sustainable, and citizen-focused (Batty *et al.* 2012). By leveraging technology across various domains, including infrastructure, energy, transportation, healthcare, security, and public services, smart cities aim to enhance quality of life (Caragliu *et al.* 2011).

The fundamental components of smart cities include data management, sustainability, participatory governance, and innovation (Neirotti *et al.* 2014). Data management involves analyzing city-wide data to inform decision-making processes. Sustainability covers topics such as energy efficiency, waste management, and environmental protection. Participatory governance encourages active citizen involvement in urban management, while innovation promotes the continuous development of new technologies and solutions (Hashem *et al.* 2016).

The success of smart cities typically relies on three key principles: technological infrastructure, data integration, and collaboration (Kitchin 2014). Technological infrastructure includes broadband internet, sensor networks, and data centers. Data integration ensures compatibility among datasets from various sources, while collaboration necessitates effective partnerships among public, private, and citizen stakeholders (Komninos 2013). Figure 2 illustrates the potential applications of IoT in smart cities, highlighting key areas such as energy management, transportation optimization, waste management, public safety, environmental monitoring, and smart infrastructure.

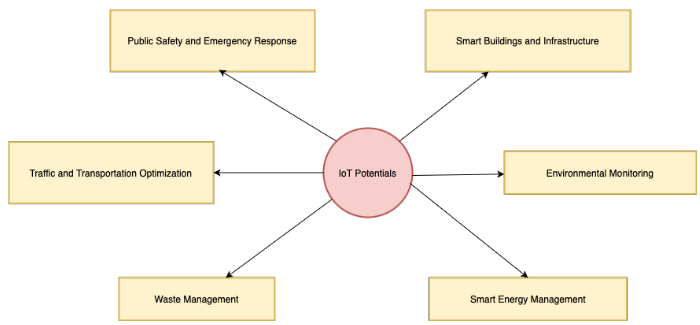

Figure 2 IoT potentials for smart cities

The Relationship Between IoT and Smart Cities IoT and smart cities are two interdependent and mutually reinforcing concepts. As a foundational element of smart cities, IoT enhances data collection and analysis capabilities citywide, enabling urban management to make more informed and effective decisions (Zanella *et al.* 2014). This integration increases operational efficiency in various sectors while delivering economic benefits (Gubbi *et al.* 2013).

Efficiency and Cost Savings: IoT applications in smart cities optimize resource management. For instance, smart energy management systems monitor and optimize energy consumption to save costs (Ahvenniemi *et al.* 2017). Smart transportation systems regulate traffic flow, reducing fuel consumption and minimizing time loss (Shaheen and Cohen 2013).

New Business Opportunities and Employment: The integration of IoT technologies creates new business opportunities and increases employment. Smart city projects generate job opportunities in areas such as data analysis, cybersecurity, software development, and IoT device maintenance (Manyika *et al.* 2015).

Revenue Growth and Economic Development: IoT-driven innovations enable the emergence of new business models and services, contributing to local economies and fostering economic growth. For example, smart healthcare applications enhance public health outcomes and create new employment opportunities in the healthcare sector (Hollands 2008).

Sustainability and Environmental Impacts: IoT facilitates achieving sustainability goals in smart cities. Smart water management systems ensure efficient use of water resources, while smart waste management systems improve waste collection and processing efficiency (Bibri 2018). These applications reduce environmental costs while helping cities meet sustainability objectives.

Data Security and Privacy: The use of IoT in smart cities involves collecting and processing large volumes of data, leading to significant challenges in data security and privacy. These challenges increase economic costs and necessitate additional security measures to prevent data breaches (Roman *et al.* 2013). In summary, the relationship between IoT and smart cities enhances efficiency, sustainability, and livability while fostering economic growth and innovation. However, it is crucial to address the challenges and costs associated with this integration through effective strategies and policies.

Economic Impacts:Positive Aspects This section provides an in-depth examination of the positive economic impacts of IoT technologies in smart cities. These impacts are generally categorized into efficiency improvements, cost savings, the emergence of new job opportunities, revenue growth, and technological innovations.

Efficiency Improvements and Cost Savings: One of the most significant advantages of IoT technologies in smart cities is the enhancement of operational efficiency and reduction of costs. Data collected through sensors and connected devices enables the optimization of city services. For instance, smart lighting systems use real-time data to minimize energy consumption by automatically adjusting light levels, resulting in significant energy savings (Ahvenniemi *et al.* 2017). Similarly, smart water management systems monitor usage, detect leaks early, and prevent water waste (Bibri 2018).

In addition, smart transportation systems regulate traffic flow, reducing fuel consumption and shortening travel times. These systems provide cost savings for both individual users and public transportation networks (Shaheen and Cohen 2013). Smart waste management systems optimize garbage collection processes, reducing costs and increasing the efficiency of waste management (Batty *et al.* 2012). Emergence of New Job Opportunities and Employment: The integration of IoT technologies in smart city projects leads to the creation of new job opportunities and an increase in employment. Fields such as data analytics, cybersecurity, software development, and IoT device maintenance and management offer new career prospects (Manyika *et al.* 2015). For example, data analysts play a critical role in managing and analyzing IoT device data streams within smart city projects (Porter and Heppelmann 2014).

Moreover, the widespread adoption of IoT technologies fosters collaboration between the public and private sectors. This collaboration encourages the development of new business models and partnerships, promoting the emergence of innovative ventures that contribute to economic growth (Gubbi *et al.* 2013). Revenue Growth and Economic Development: Innovative solutions offered by IoT enable the development of new business models and services, contributing to local economies and driving economic growth. IoT applications in smart cities improve efficiency in sectors such as energy, healthcare, transportation, and public safety, revitalizing economic activity in these areas (Hollands 2008).

For example, smart healthcare applications make healthcare services more accessible and effective, improving public health outcomes and creating new job opportunities in the healthcare sector (Zanella *et al.* 2014). Additionally, IoT-powered data analytics enables businesses to make informed decisions and optimize market strategies, contributing to increased revenue (Neirotti *et al.* 2014). Innovation and Technological Development: IoT technologies continuously promote innovation and technological advancement in smart cities. IoT's data collection and analysis capabilities support research and development (RD) activities, enabling the creation of new technologies (Atzori *et al.* 2010). This strengthens the technological infrastructure of cities while enhancing their innovation capacities.

Innovative IoT solutions contribute to achieving sustainability goals while increasing economic competitiveness. For instance, smart energy management systems facilitate the efficient use of renewable energy sources, supporting the development of innovative solutions in the energy sector (Ahvenniemi *et al.* 2017).

Economic Impacts:Negative Aspects and Costs The economic impacts of IoT technologies in smart cities are not limited to positive aspects. Their integration also entails various costs and challenges. This section delves into the potential negative economic impacts and costs associated with IoT in smart cities.

High Initial Costs: The establishment of IoT infrastructure requires significant initial investments in smart city projects. The installation of sensors, connectivity infrastructure, data centers, and other equipment incurs high costs (Zanella *et al.* 2014). These expenses can pose a considerable financial burden, especially for developing cities, making project implementation more challenging (Ahvenniemi *et al.* 2017). Additionally, investments in standardizing and ensuring the compatibility of IoT devices also contribute to increased costs. Making devices from different manufacturers interoperable requires additional technical and financial resources (Gubbi *et al.* 2013).

Maintenance and Update Costs: The costs of IoT infrastructure are not limited to initial investments; ongoing maintenance, updates, and improvements also impose a significant financial burden. Regular maintenance of IoT devices, software updates, and ensuring system security require continuous investment (Roman *et al.* 2013). Furthermore, the rapid evolution of IoT technologies necessitates regular updates and replacements of existing systems. This creates additional costs for city administrations and complicates budget planning (Porter and Heppelmann 2014).

Workforce Transformation and Social Costs: The integration of IoT technologies can lead to increased automation and the elimination of certain jobs, resulting in workforce transformations and job losses in specific sectors (Zanella *et al.* 2014). Low-skilled workers, in particular, may be adversely affected by automation processes driven by IoT, potentially leading to higher unemployment rates (Neirotti *et al.* 2014). Such transformations can exacerbate social costs, creating economic inequalities within societies. To address workforce transformations, retraining programs and opportunities for professional development are essential (Hashem *et al.* 2016).

Data Management and Privacy Costs: The use of IoT technologies in smart cities involves collecting and processing large volumes of data. Managing, storing, and securing this data incurs substantial costs (Roman *et al.* 2013). Technological solutions and security measures required to ensure data security and privacy create additional financial burdens for city administrations. Moreover, data breaches and cyberattacks can result in both economic losses and reputational damage. Therefore, continuous investments in data security and privacy are critical for ensuring the economic sustainability of cities (Porter and Heppelmann 2014).

Legal and Regulatory Challenges: The application of IoT technologies in smart cities also faces legal and regulatory challenges. Data protection laws in different regions may complicate the integration of IoT applications and lead to additional costs (Ahvenniemi *et al.* 2017). Furthermore, the lack of international regulations on the standardization and compatibility of IoT devices can limit intercity collaboration and data sharing (Gubbi *et al.* 2013).

Infrastructure and Technological Compatibility Issues:Successful integration of IoT technologies requires updating existing infrastructure to accommodate these new technologies. This process may involve renewing or completely replacing legacy systems, leading to additional costs and time requirements (Zanella *et al.* 2014). Ensuring compatibility among various IoT devices and platforms also presents technical challenges that can affect project feasibility (Gubbi *et al.* 2013).

Societal Acceptance and User Resistance: The successful adoption of IoT technologies depends on societal trust and acceptance. A lack of public confidence or resistance to new technologies can negatively impact the economic efficiency and success of projects (Neirotti *et al.* 2014). Addressing these issues may require additional educational programs and awareness campaigns, which can lead to extra costs (Hashem *et al.* 2016).

Application Areas This section provides a detailed examination of the various application areas of the Internet of Things (IoT) in smart cities and presents case studies of successful projects within these areas. The application areas include transportation and traffic management, energy management, waste management, public safety and emergency management, as well as healthcare and social services.

Smart transportation systems leverage IoT technologies to optimize traffic flow, improve public transportation efficiency, and reduce carbon emissions (Shaheen and Cohen 2013). For instance, smart traffic lights use real-time data analytics to monitor traffic congestion and automatically adjust light durations (Batty et al., 2012), thereby decreasing traffic jams and shortening travel times (Zanella *et al.* 2014). Smart energy management systems utilize IoT technologies to monitor and optimize energy consumption while integrating renewable energy sources (Ahvenniemi *et al.* 2017). Smart grids track energy distribution in real-time, balancing supply and demand and minimizing energy losses (Bibri 2018).

Smart waste management systems use IoT technologies to optimize waste collection, reduce waste volume, and increase recycling rates (Batty et al., 2012). Smart bins equipped with sensors monitor fill levels and optimize waste collection routes, improving the efficiency of waste management (Bibri 2018). Smart security systems enhance public safety and enable rapid response to emergencies using IoT technologies (Roman *et al.* 2013). IoT-based smart cameras, sensors, and data analytics play a critical role in crime prevention, incident response, and emergency management (Hashem *et al.* 2016). Smart healthcare applications use IoT technologies to make healthcare services more accessible and effective (Zanella *et al.* 2014). Remote health monitoring, smart devices, and data analytics allow continuous monitoring of patients' health and enable early interventions (Madakam *et al.* 2015).

Challenges and Barriers While the integration of the Internet of Things (IoT) into smart cities offers significant economic benefits, it also faces various challenges and barriers. This section examines the major obstacles and potential negative economic impacts associated with IoT in smart cities. Successful IoT integration requires a robust and compatible technological infrastructure. This process often necessitates updating or entirely replacing existing infrastructure to accommodate modern IoT technologies (Zanella *et al.* 2014). Integrating older systems with IoT devices can present technical challenges and incur additional costs (Gubbi *et al.* 2013). Furthermore, standardizing IoT devices and ensuring their interoperability require substantial engineering effort and financial investment. Ensuring that devices from different manufacturers work seamlessly together is a significant barrier during the integration process (Porter and Heppelmann 2014), leading to additional costs and time delays for city administrations (Ahvenniemi *et al.* 2017).

Establishing and maintaining IoT infrastructure involves substantial upfront costs. These include installing sensors, connectivity infrastructure, data centers, and other equipment (Zanella *et al.* 2014). For developing cities, these costs can pose a significant financial burden due to budget constraints (Ahvenniemi *et al.* 2017). Moreover, the return on investment (ROI) for IoT projects is often uncertain, raising doubts about their profitability (Manyika *et al.* 2015). This uncertainty may deter both public and private sector stakeholders from investing in IoT initiatives (Gubbi *et al.* 2013). The application of IoT technologies in smart cities brings regulatory and legal challenges. Data protection laws can complicate IoT integration and increase associated costs (Roman *et al.* 2013). Variations in data protection regulations across regions can further hinder intercity collaboration and data sharing (Ahvenniemi *et al.* 2017). Additionally, the lack of international standards for IoT device compatibility and standardization creates barriers to integration across cities (Gubbi *et al.* 2013). Such regulatory uncertainties pose significant challenges during the planning and implementation of IoT projects (Porter and Heppelmann 2014).

The use of IoT in smart cities requires the collection and processing of vast amounts of data, raising serious security and privacy concerns (Roman *et al.* 2013). Cyberattacks, data breaches, and malicious use of IoT systems threaten the security of IoT infrastructure (Hashem *et al.* 2016). Addressing these concerns requires city administrations to implement advanced security measures and technological solutions. Maintaining data security involves continuously updating security protocols and infrastructure, which imposes significant costs and complicates budget planning (Porter and Heppelmann 2014). The successful adoption of IoT technologies depends on societal trust and acceptance. A lack of public confidence or resistance to new technologies can negatively impact the economic efficiency and success of IoT projects (Neirotti *et al.* 2014). Addressing these issues may require additional educational programs and awareness campaigns, further increasing costs (Hashem *et al.* 2016). Furthermore, insufficient public knowledge about IoT technologies can hinder their effective utilization and prevent projects from achieving their goals (Neirotti *et al.* 2014).

RESULTS

To effectively leverage IoT's economic impacts in smart cities and overcome the associated challenges, various strategic perspectives and recommendations must be developed. This section outlines the future role of IoT in smart cities and strategies to maximize its economic potential. Figure 3 illustrates future perspectives and strategic recommendations for leveraging IoT's economic impacts in smart cities. Key areas include technological advancements, such as AI integration, machine learning, and 5G connectivity, alongside strategic planning through long-term goals, resource allocation, and public-private partnerships. Sustainability efforts focus on energy efficiency, waste management, and renewable integration, while economic resilience is driven by diversified sectors, job creation, and IoT-driven innovations. This visualization highlights the interconnected strategies necessary to maximize IoT's potential in urban environments.

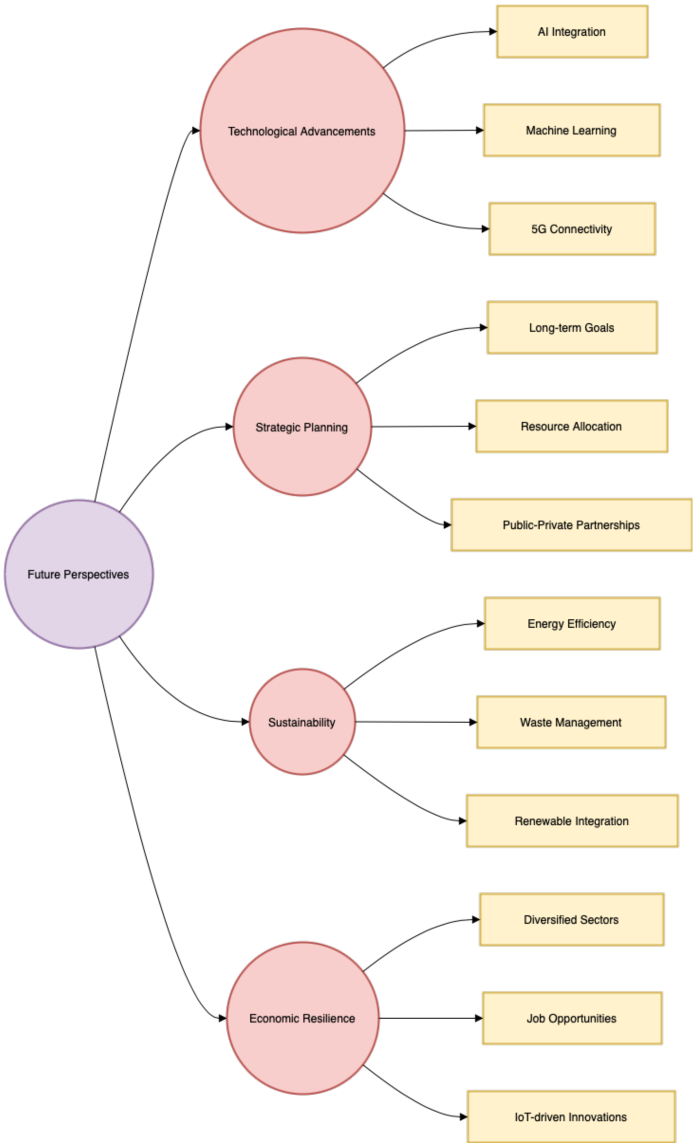

Figure 3 Future Perspectives of IoT

IoT technologies are expected to advance further, with innovative solutions emerging in the future. Integrating IoT with advanced technologies such as artificial intelligence (AI) and machine learning (ML) will enhance data analytics and decision-making processes in smart cities (Gubbi *et al.* 2013). These advancements will enable city administrations to make more informed and effective decisions, thereby improving economic efficiency (Porter and Heppelmann 2014). The proliferation of high-speed, reliable connectivity technologies such as 5G will also enhance the performance of IoT devices, increasing the success of smart city projects (Ahvenniemi *et al.* 2017).

Effective strategic planning and policymaking are essential to maximize IoT's economic impacts in smart cities. City administrations and policymakers should establish long-term goals for IoT projects and allocate the necessary resources to achieve them (Batty *et al.* 2012). Strong partnerships between public and private sectors should be established to ensure the financial and technical support needed for IoT projects. Such collaborations will enhance the success of IoT initiatives (Manyika *et al.* 2015).

To sustain IoT's economic impacts in smart cities, it is crucial to adopt principles of environmental and economic sustainability. IoT technologies can support sustainability goals such as energy efficiency, waste management, and the integration of renewable energy sources, thereby enhancing economic resilience (Ahvenniemi *et al.* 2017). Additionally, diversifying economic sectors within cities and creating new job opportunities through IoT-driven innovations can strengthen economic resilience (Porter and Heppelmann 2014). Strong public-private partnerships (PPPs) are vital for the successful implementation of IoT projects. Such collaborations provide the financial and technical support required for these initiatives (Gubbi *et al.* 2013). International collaborations and knowledge sharing can help identify best practices and success factors. Experiences gained from IoT projects in different cities can be applied to other cities, enhancing economic efficiency (Neirotti *et al.* 2014).

CONCLUSION

Our analysis demonstrates that ensemble models such as Random Forest and Gradient Boosting are highly effective in predicting customer purchase behavior. Logistic Regression, while simpler and more interpretable, provides lower accuracy and ROC AUC scores compared to ensemble models. Support Vector Machine and K-Nearest Neighbors offer robust alternatives, with KNN being particularly effective for datasets with a clear neighborhood structure. XGBoost, known for its efficiency and performance, also delivers excellent results. The insights gained from this study can help businesses make data-driven decisions, improve customer targeting, and design more effective marketing strategies. Additionally, this study contributes to the growing body of research on the application of machine learning in customer analytics, providing a reference for future studies and practical implementations.

Future studies could examine IoT's economic impacts in smart cities from a broader perspective and include more case studies. Research focusing on the economic effects of smart city projects in developing countries could expand the existing literature. Furthermore, studies exploring the sustainability impacts of IoT could provide valuable insights into enhancing cities' long-term economic resilience . Research on data security and privacy could help develop strategies to manage IoT's economic impacts more securely and sustainably . Finally, studies investigating the integration of advanced technologies such as AI and ML with IoT in smart cities could reveal the potential benefits and opportunities offered by these technologies, guiding future smart city projects.

Availability of data and material

Not applicable.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Ethical standard

The author has no relevant financial or non-financial interests to disclose.

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