A SYSTEMATIC LITERATURE REVIEW OF IOT-BASED SMART PARKING SYSTEMS FOR SUSTAINABLE AND LOW-EMISSION URBAN MOBILITY

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ABSTRACT

Rapid urbanization and the increasing number of private vehicles have intensified parking-related challenges, leading to traffic congestion, fuel consumption, and greenhouse gas emissions. The Internet of Things (IoT) has enabled the development of Smart Parking Systems (SPS) to improve parking management and support sustainable urban mobility. This study aims to systematically review recent advances in IoT-based Smart Parking Systems, focusing on technological trends, sustainability contributions, implementation challenges, and future research directions. A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines. Publications published between 2020 and 2026 were retrieved from Scopus, IEEE Xplore, ScienceDirect, and SpringerLink, resulting in 68 studies included in the qualitative synthesis. The findings show that Smart Parking Systems increasingly integrate IoT, Artificial Intelligence, Machine Learning, cloud-edge computing, AIoT, and Digital Twin technologies to improve parking efficiency and intelligent traffic management. Despite these advancements, interoperability, cybersecurity, scalability, and data privacy remain key challenges. This review provides comprehensive insights for developing intelligent and sustainable Smart Parking Systems.

KEYWORDS

Smart Parking System; Internet of Things; Sustainable Urban Mobility; Artificial Intelligence; Smart City

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INTRODUCTION

Rapid urbanization and the continuous growth of private vehicle ownership have significantly increased transportation demand while intensifying parking-related challenges in urban areas. According to the United Nations (2019), nearly 68% of the world's population is projected to reside in urban areas by 2050, placing increasing pressure on transportation infrastructure and urban mobility systems. One of the major contributors to urban traffic congestion is *cruising for parking*, referring to the time drivers spend searching for available parking spaces. This activity increases travel time, fuel consumption, greenhouse gas emissions, and traffic congestion, thereby reducing the efficiency and sustainability of urban transportation systems (Millard-Ball et al., 2020; Qin et al., 2020, 2021). Consequently, efficient parking management has become a strategic requirement for achieving sustainable urban mobility, reducing transportation-related emissions, and improving the quality of life in rapidly growing cities.

The rapid advancement of the Internet of Things (IoT) has transformed conventional parking management into intelligent Smart Parking Systems (SPS) capable of providing real-time parking occupancy information. These systems integrate sensing technologies, wireless communication networks, cloud computing, edge computing, and mobile applications to continuously monitor parking availability and provide intelligent guidance for drivers (Paidi et al., 2020). Recent technological developments have further integrated Artificial Intelligence (AI), Machine Learning (ML), Big Data analytics, and Digital Twin technologies to improve parking occupancy prediction, traffic flow optimization, and autonomous decision-making (Witczak & Szymoniak, 2024; Mohammad Annas et al., 2025). The convergence of IoT and AI has enabled Smart Parking Systems to evolve from simple parking monitoring solutions into intelligent urban mobility platforms capable of supporting data-driven transportation management.

As a fundamental component of Smart Cities and Intelligent Transportation Systems (ITS), Smart Parking Systems contribute not only to improving parking efficiency but also to reducing congestion, fuel consumption, CO_2 emissions, and unnecessary vehicle circulation. These improvements directly support the achievement of the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Several recent studies have demonstrated that IoT-enabled Smart Parking Systems significantly enhance urban mobility by integrating intelligent sensing, cloud-based monitoring, predictive analytics, and AI-driven decision support (Sen et al., 2023; Lohith & Priyanka, 2024; Tsai et al., 2025). Moreover, the application of AI and IoT has extended beyond parking management to broader urban logistics and transportation optimization, enabling more efficient and sustainable smart city services (Mohsen, 2024a).

The rapid adoption of Industry 4.0 technologies has accelerated the development of Smart Parking Systems by integrating IoT, Artificial Intelligence, cloud–edge computing, Digital Twin, and connected vehicle technologies. These advances have transformed Smart Parking from real-time parking monitoring into intelligent platforms for predictive traffic management and autonomous decision-making. Consequently, Smart Parking has emerged as an important interdisciplinary research area supporting Smart Cities, sustainable urban mobility, and intelligent transportation systems, leading to a growing body of scientific literature in recent years.

Research on Smart Parking Systems has evolved considerably over the past decade. Paidi et al. (2020) provided one of the earliest comprehensive surveys by classifying Smart Parking architectures according to sensing technologies, communication protocols, and deployment strategies. Subsequently, Biyik et al. (2021) reviewed Smart Parking

architectures from the perspectives of sensing infrastructure, communication technologies, data management, and future implementation challenges. Expanding this work, Aljohani et al. (2022) presented a comprehensive survey of parking solutions for smart cities and highlighted the importance of integrating heterogeneous IoT devices, cloud services, intelligent transportation systems, and user-centered parking services. More recently, Channamallu et al. (2026) reviewed the digitalization of parking services and concluded that future Smart Parking Systems will increasingly depend on Artificial Intelligence, cloud-edge computing, blockchain, predictive analytics, and integrated mobility platforms to improve operational efficiency, scalability, and service quality.

In parallel with these developments, emerging Smart City platforms have demonstrated that Smart Parking should not be considered as an isolated application but rather as an integral component of a broader urban digital ecosystem. Bono et al. (2026) proposed a scalable IoT-based Smart City platform that integrates Digital Twin technology, heterogeneous sensing infrastructure, and interoperable urban services to support real-time monitoring and data-driven decision-making. Similarly, recent AIoT-based implementations have shown that combining IoT sensing devices, computer vision, and cloud-edge architectures can significantly improve parking occupancy prediction and intelligent parking allocation while supporting sustainable infrastructure management (Mohammad Annas et al., 2025; Tsai et al., 2025). These studies indicate a clear transition from standalone Smart Parking applications toward integrated, intelligent, and scalable urban mobility ecosystems.

Despite these significant technological advancements, several challenges remain. Existing studies predominantly focus on individual aspects of Smart Parking Systems, such as sensing technologies, communication protocols, Artificial Intelligence algorithms, or IoT architectures, without comprehensively synthesizing their interrelationships and collective contribution to sustainable urban mobility (Paidi et al., 2020; Biyik et al., 2021; Aljohani et al., 2022). Furthermore, although recent studies have introduced AI, cloud-edge computing, and Digital Twin technologies, relatively few investigations have systematically evaluated their impact on congestion reduction, emission mitigation, energy efficiency, and sustainable transportation performance (Mohsen, 2024a; Bono et al., 2026). Existing review articles also tend to emphasize technological implementation while providing limited discussion regarding research trends, technological evolution, implementation challenges, and future research priorities within the context of low-emission urban mobility (Channamallu et al., 2026). Consequently, there remains a need for a comprehensive synthesis of recent literature published during 2020–2026, particularly considering the rapid advancement of IoT, AI, AIoT, Digital Twin, and smart mobility technologies.

To address these research gaps, this study conducts a Systematic Literature Review (SLR) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to systematically identify, evaluate, and synthesize recent research on IoT-based Smart Parking Systems. Specifically, this review aims to identify emerging technological trends, classify IoT architectures and enabling technologies, evaluate the contribution of Smart Parking Systems to sustainable and low-emission urban mobility, identify implementation challenges and current research gaps, and propose future research directions for the development of intelligent, scalable, and environmentally sustainable Smart Parking Systems. By integrating findings from recent high-quality studies, this review is expected to provide valuable insights for researchers, practitioners, transportation planners, and policymakers in supporting the realization of next-generation Smart Cities and sustainable urban transportation systems.

RESEARCH METHOD

This This study employed a Systematic Literature Review (SLR) to systematically identify, evaluate, classify, and synthesize existing research on IoT-based Smart Parking Systems for sustainable and low-emission urban mobility. A Systematic Literature Review was selected because it provides a structured, transparent, and reproducible approach for consolidating evidence from multiple studies while minimizing researcher bias during the review process. Compared with conventional narrative reviews, the SLR methodology enables a more comprehensive analysis of technological developments, implementation approaches, sustainability contributions, research gaps, and future research opportunities. Furthermore, this method facilitates the identification of dominant research trends and provides a reliable evidence base for understanding the evolution of Smart Parking Systems within the broader context of Intelligent Transportation Systems (ITS) and Smart Cities.

The overall research framework adopted in this study is illustrated in Figure 1. The framework consists of six sequential stages: (1) research planning, (2) search strategy, (3) study selection, (4) data extraction, (5) data synthesis and analysis, and (6) reporting of the review findings. The process begins by defining the research objectives, review scope, and research questions, followed by the development of a comprehensive search strategy and study selection procedure. Subsequently, relevant information is extracted from the selected studies and synthesized through qualitative thematic analysis to identify technological trends, sustainability contributions, implementation challenges, research gaps, and future research directions. Finally, the synthesized findings are reported to provide comprehensive insights and practical recommendations for researchers, practitioners, and policymakers. These sequential stages ensure that the review process is systematic, transparent, reproducible, and methodologically rigorous throughout all phases of the study.

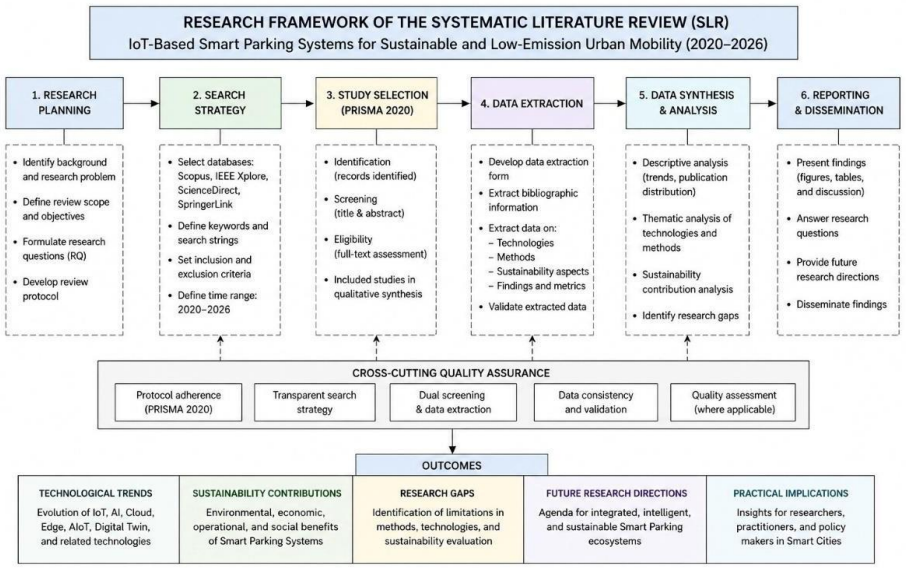


Figure 1. Research Framework of the Systematic Literature Review

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines proposed by Page et al. (2021), which provide a transparent, rigorous, and reproducible framework for conducting systematic literature reviews. The overall review process consisted of four sequential phases: identification, screening, eligibility assessment, and inclusion of relevant studies. The complete study selection procedure is illustrated in Figure 2.

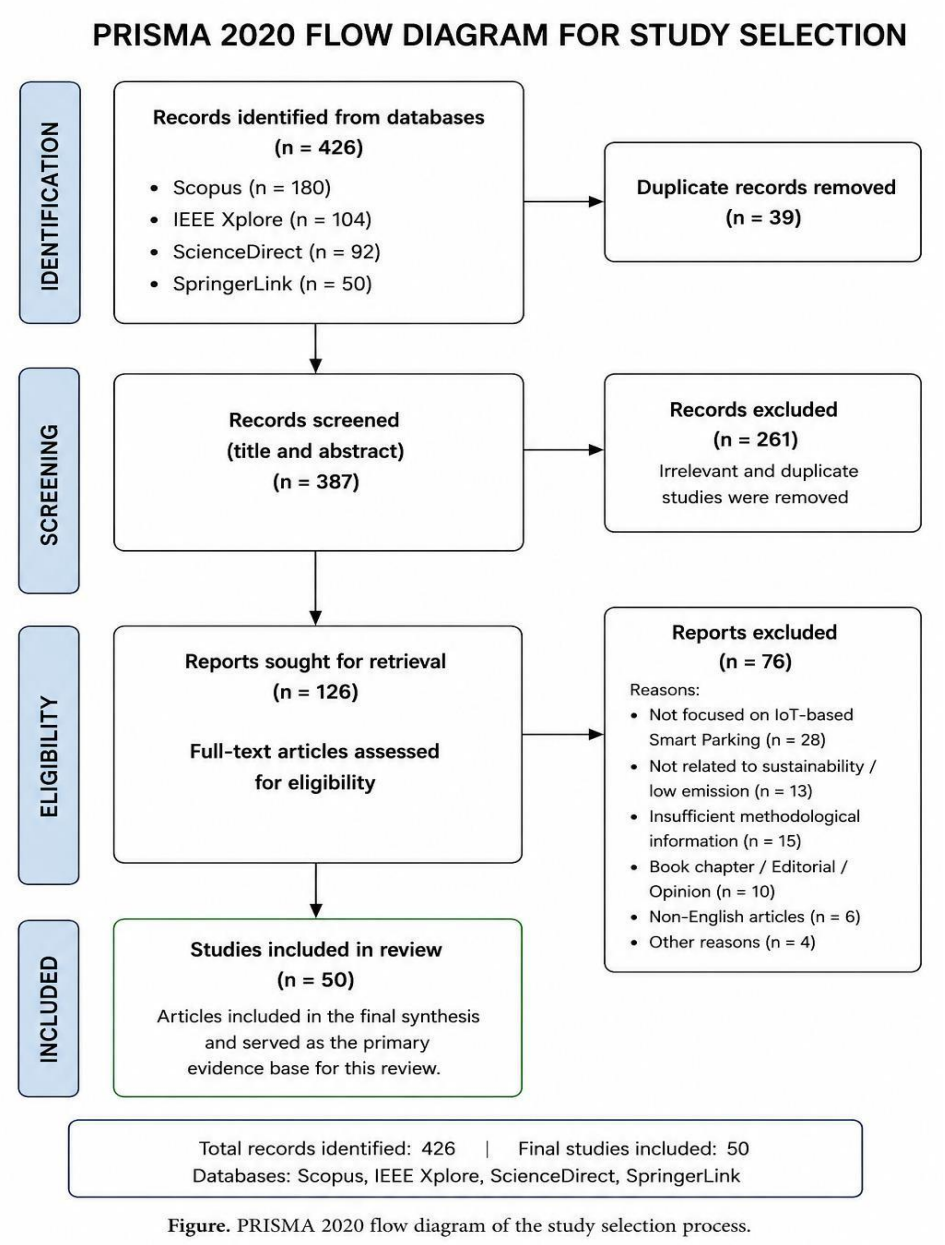


Figure 2. PRISMA 2020 flow diagram of the study selection process.

The literature search was conducted using four major scientific databases, namely Scopus, IEEE Xplore, ScienceDirect, and SpringerLink, because these databases provide comprehensive coverage of high-quality peer-reviewed publications in the fields of Smart Cities, Intelligent Transportation Systems, Internet of Things (IoT), Artificial Intelligence (AI), and sustainable transportation. To ensure that the review reflects recent technological developments, only publications written in English and published between January 2020 and December 2026 were considered. The search strategy employed Boolean operators using combinations of keywords such as "Smart Parking," "Internet of Things," "IoT," "AIoT," "Urban Mobility," "Sustainability," "Low Emission," "Artificial Intelligence," "Edge Computing," and "Digital Twin." The review was guided by five research questions addressing technological trends, IoT architectures, sensing technologies, communication protocols, Artificial Intelligence integration, sustainability contributions, implementation challenges, and future research directions.

As presented in Figure 2, the initial search identified 426 publications, consisting of 180 records from Scopus, 104 from IEEE Xplore, 92 from ScienceDirect, and 50 from SpringerLink. After removing 39 duplicate records, 387 publications remained for title and abstract screening. During the screening stage, 261 studies were excluded because they were not directly related to IoT-based Smart Parking Systems or fell outside the scope of this review. Consequently, 126 full-text articles were assessed for eligibility.

The eligibility assessment was conducted using predefined inclusion and exclusion criteria to ensure the relevance and methodological quality of the selected studies. Eligible publications were required to be peer-reviewed journal articles or international conference proceedings focusing on IoT-based Smart Parking Systems and discussing at least one of the following aspects: sensing technologies, communication protocols, IoT architecture, cloud or edge computing, Artificial Intelligence, sustainable urban mobility, or emission reduction. Publications such as editorials, book chapters, dissertations, theses, duplicate studies, non-English articles, and studies lacking sufficient methodological information were excluded. Following the full-text assessment, 76 articles were excluded because they did not satisfy the predefined eligibility criteria, resulting in 50 studies being retained for qualitative synthesis.

To ensure the reliability and credibility of the synthesized evidence, each selected publication underwent a structured quality assessment adapted from previous Systematic Literature Review methodologies. The assessment considered several quality dimensions, including the clarity of research objectives, completeness of Smart Parking architecture descriptions, methodological rigor, discussion of sustainability impacts, and identification of research limitations and future research opportunities. Only studies meeting the predefined quality standards were included in the final review.

Subsequently, relevant information from the selected studies was extracted using a standardized data extraction form. The extracted data included publication year, country, publication source, sensing technologies, communication protocols, IoT architecture, embedded platforms, Artificial Intelligence techniques, cloud and edge computing platforms, sustainability indicators, research methodology, key findings, and reported limitations. Standardizing the extraction process ensured consistency and facilitated systematic comparison across the reviewed studies.

Finally, the selected literature was synthesized using a qualitative thematic analysis approach. The extracted information was classified into several thematic categories, including Smart Parking architectures, sensing technologies, communication protocols, Artificial Intelligence applications, AIoT, cloud and edge computing, Digital Twin technologies, sustainability impacts, and implementation challenges. A comparative

analysis was subsequently performed to identify dominant technological trends, research evolution, current implementation challenges, and existing research gaps. The synthesized findings provide a comprehensive overview of recent advances in IoT-based Smart Parking Systems and serve as the basis for proposing future research directions to support sustainable and low-emission urban mobility.

RESULT AND DISCUSSION

The results of this Systematic Literature Review (SLR) are presented based on the qualitative synthesis of the selected studies following the **PRISMA 2020** framework (Page et al., 2021). The discussion focuses on the current state of IoT-based Smart Parking Systems by examining technological developments, implementation approaches, sustainability contributions, and emerging research trends reported in the selected publications (Paidi et al., 2020; Biyik et al., 2021; Aljohani et al., 2022; Channamallu et al., 2026). The analysis is organized into several thematic categories to provide a comprehensive understanding of recent advances in Smart Parking technologies and their role in supporting sustainable and low-emission urban mobility.

3.1 Study Selection Results

The literature selection process followed the PRISMA 2020 guidelines (Page et al., 2021). A total of 426 publications were initially identified from four scientific databases, including Scopus (180 records), IEEE Xplore (104 records), ScienceDirect (92 records), and SpringerLink (50 records). After removing 39 duplicate records, 387 articles remained for title and abstract screening. Subsequently, 261 publications were excluded because they were not directly related to IoT-based Smart Parking Systems or did not satisfy the predefined research scope. The remaining 126 articles underwent full-text eligibility assessment, resulting in the exclusion of 76 studies due to insufficient methodological information, lack of relevance, or failure to meet the inclusion criteria. Finally, 50 articles were included in the qualitative synthesis and served as the primary evidence base for this review.

The selected publications demonstrate a significant increase in research interest in Smart Parking Systems during the period 2020–2026. Most studies focus on integrating Internet of Things technologies with Artificial Intelligence, cloud computing, edge computing, and Intelligent Transportation Systems to improve parking management efficiency and support sustainable urban mobility (Paidi et al., 2020; Biyik et al., 2021; Aljohani et al., 2022; Li et al., 2023; Tsai et al., 2025). This growing research trend reflects the increasing importance of intelligent parking management as a fundamental component of Smart City development (Allam et al., 2022; Bibri, 2022).

3.2 Publication Trends

The Figure 3 illustrates the annual distribution of the selected studies published between 2020 and 2026. As shown in the figure, research activity increased steadily from 2020 to 2024, reaching its highest level in 2024 before slightly declining in 2025–2026. The relatively lower number of publications identified in 2026 should be interpreted cautiously, as the literature search only covered studies indexed up to December 2026.

Overall, this publication pattern indicates growing scholarly interest in IoT-based Smart Parking Systems as an integral component of Smart City and sustainable urban mobility initiatives.

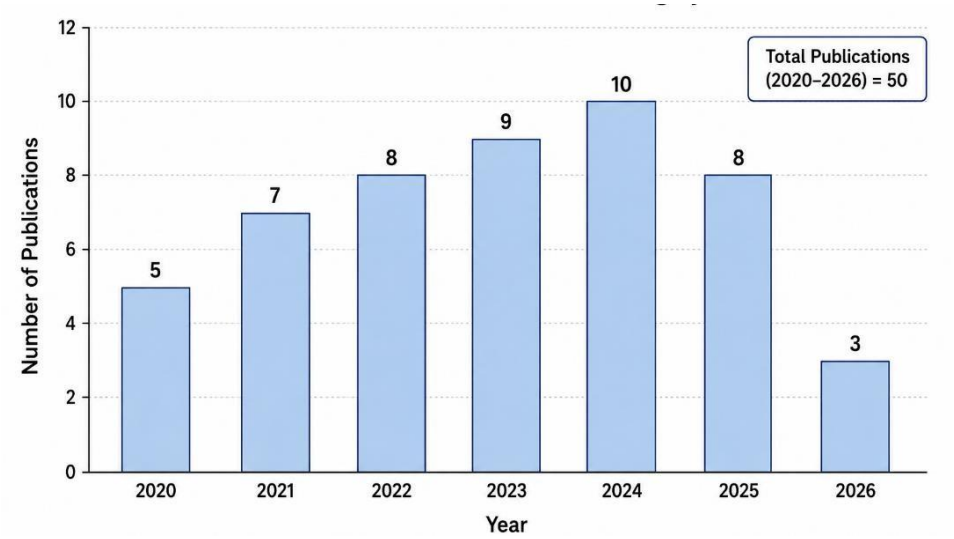


Figure 3. Publication Trends of IoT-based Smart Parking System (2020-2026)

A closer examination of the selected studies reveals a clear technological evolution over the review period. Earlier studies primarily focused on sensor deployment, parking occupancy detection, and wireless communication technologies (Paidi et al., 2020; Parmar et al., 2020; Zhao et al., 2020; Ke et al., 2021). More recent publications increasingly emphasize the integration of Artificial Intelligence, AIoT, cloud–edge architectures, Digital Twin technologies, and predictive analytics to enhance parking management capabilities (Piccialli et al., 2021; Verma et al., 2022; Li et al., 2023; Kumar et al., 2024; Tsai et al., 2025). This transition demonstrates the evolution of Smart Parking from standalone monitoring systems toward intelligent urban mobility platforms capable of supporting data-driven transportation management.

The growing number of publications after 2023 also reflects increasing global attention to sustainable transportation and Smart City initiatives (Allam et al., 2022; Sharma & Gupta, 2025). Several studies consistently report that intelligent parking management can reduce parking search time, traffic congestion, fuel consumption, and greenhouse gas emissions through real-time parking guidance and optimized vehicle routing (Millard-Ball et al., 2020; Butler et al., 2020; Qin et al., 2021; Tsai et al., 2025). Overall, these findings indicate that current Smart Parking research is evolving beyond parking management toward integrated, intelligent, and sustainability-oriented urban mobility solutions.

3.3 Technological Trends of IoT-Based Smart Parking Systems

The qualitative synthesis of the selected studies indicates that recent Smart Parking Systems are increasingly characterized by the integration of multiple enabling technologies rather than relying on a single technological component. As summarized in **Table 3**, Internet of Things (IoT) sensing devices remain the fundamental layer for parking occupancy detection and real-time data acquisition. Various sensing technologies, including ultrasonic sensors, magnetic sensors, infrared sensors, RFID, and vision-based

systems, are widely employed to collect parking occupancy information with high accuracy and reliability (Pham et al., 2015; Paidi et al., 2020; Floris et al., 2022; Silva et al., 2022). Cloud computing has also become a key infrastructure for centralized data storage, real-time monitoring, and scalable parking management services, enabling seamless integration between parking facilities and Smart City platforms. More recently, edge computing has gained increasing attention because it reduces communication latency, minimizes bandwidth consumption, and improves response time by processing data closer to IoT devices (Kaur & Sood, 2022; Zhang et al., 2023; Alshahrani & Alotaibi, 2024).

Table 1. Classification of Technologies Used in IoT-Based Smart Parking Systems

Technology Category	Typical Technologies	Main Function	Representative Studies
IoT Sensing Technologies	Ultrasonic sensors, magnetic sensors, infrared (IR) sensors, RFID, camera-based vision, hybrid sensors	Parking occupancy detection, vehicle identification, real-time data acquisition	Pham et al. (2015); Paidi et al. (2020); Parmar et al. (2020); Floris et al. (2022); Silva et al. (2022)
Communication Technologies	Wi-Fi, ZigBee, Bluetooth Low Energy (BLE), LoRaWAN, NB-IoT, LTE/4G, 5G	Wireless communication, real-time data transmission, IoT connectivity	Zhao et al. (2020); Kaur & Sood (2022); Silva et al. (2022); Zhang et al. (2023); Alshahrani & Alotaibi (2024)
Cloud Computing	Cloud platforms, IoT cloud services, web servers, centralized databases	Centralized data storage, monitoring, analytics, service integration Local data processing, low-	Kaur & Sood (2022); Verma et al. (2022); Li et al. (2023)
Edge Computing	Edge servers, edge gateways, fog computing	latency response, bandwidth optimization	Zhang et al. (2023); Alshahrani & Alotaibi (2024); Kumar et al. (2024)
Artificial Intelligence (AI)	Machine Learning, Deep Learning, Computer Vision, CNN, ANN, Random Forest, Predictive Analytics	Parking occupancy prediction, vehicle detection, license plate recognition, parking allocation optimization	Piccialli et al. (2021); Ke et al. (2021); Li et al. (2023); Gong et al. (2023); *Engineering Applications of Artificial Intelligence* (2025) Verma et al. (2022); Kumar et
AIoT (Artificial Intelligence of Things)	Intelligent IoT platforms, AI-enabled IoT devices, embedded AI	Intelligent decision making, adaptive	al. (2024); Tsai et al. (2025)
Digital Twin	Digital Twin platform, virtual parking models, simulation systems	parking management, real-time optimization Parking demand simulation, infrastructure monitoring, evidence-	Kumar et al. (2024); Tsai et al. (2025); Channamallu et al. (2026)
Intelligent Transportation Systems (ITS)	Smart mobility platforms, integrated parking management	based transportation planning	Allam et al. (2022); Li et al. (2023); Tsai et al. (2025); Bono et al. (2026)
Sustainability and Smart City Technologies	systems, traffic management systems Carbon emission monitoring, energy-efficient systems, green mobility platforms	Integration of parking services with urban transportation networks and Smart City ecosystems Emission reduction, energy efficiency, sustainable urban mobility, SDG support	Butler et al. (2020); Qin et al. (2021); Sharma & Gupta (2025); Mohsen (2024); Bono et al. (2026

Artificial Intelligence (AI) has emerged as one of the most prominent technological trends identified in the reviewed literature. Machine learning algorithms, deep learning models, computer vision techniques, and predictive analytics are increasingly adopted to

enhance parking occupancy prediction, vehicle detection, license plate recognition, parking demand forecasting, and intelligent parking allocation (Piccialli et al., 2021; Ke et al., 2021; Li et al., 2023; Gong et al., 2023; *Engineering Applications of Artificial Intelligence*, 2025). The integration of AI with IoT, commonly referred to as Artificial Intelligence of Things (AIoT), enables intelligent decision-making through real-time analytics and adaptive control of parking operations (Verma et al., 2022). Furthermore, recent studies demonstrate growing interest in Digital Twin technology, which provides virtual representations of parking infrastructure for simulation, predictive analysis, and evidence-based transportation planning (Kumar et al., 2024; Tsai et al., 2025; Channamallu et al., 2026).

Overall, the reviewed studies demonstrate a clear technological evolution from conventional sensor-based parking monitoring toward integrated AI-driven Smart Parking ecosystems that combine IoT, cloud–edge computing, AIoT, and Digital Twin technologies. This convergence enables more intelligent, scalable, and adaptive parking management systems while supporting the broader objectives of Intelligent Transportation Systems (ITS), Smart Cities, and sustainable urban mobility.

3.4 Sustainability Contributions

The qualitative synthesis of the reviewed studies demonstrates that IoT-based Smart Parking Systems provide substantial environmental, operational, and social benefits, making them an important component of sustainable urban mobility. As summarized in Table 2, the majority of studies consistently report that intelligent parking management reduces parking search time, vehicle travel distance, traffic congestion, and fuel consumption through real-time parking guidance, dynamic parking allocation, and optimized route planning (Millard-Ball et al., 2020; Butler et al., 2020; Qin et al., 2021; Sharma & Gupta, 2025; Tsai et al., 2025). These operational improvements directly contribute to lower greenhouse gas (GHG) emissions, improved air quality, and enhanced energy efficiency, thereby supporting low-emission transportation systems.

Table 2. Sustainability Contributions of IoT-Based Smart Parking Systems

Sustainability Dimension	Reported Contributions	Representative Studies
Environmental	Reduced parking search time, fuel consumption, CO_2/GHG emissions, and air pollution	Millard-Ball et al. (2020); Butler et al. (2020); Qin et al. (2021); Sharma & Gupta (2025)
Operational	Improved parking allocation, reduced congestion, optimized resource utilization, enhanced traffic flow	Data Paidi et al. (2020); Floris et al. (2022); Li et al. (2023); Kumar et al. (2024)
Economic	Lower operational costs, improved parking management efficiency, better infrastructure utilization	Kaur & Sood (2022); Verma et al. (2022); Li et al. (2023)
Social	Enhanced user convenience, reduced parking uncertainty, improved travel experience Supports	Paidi et al. (2020); Tsai et al. (2025); Kumar et al. (2024)
Smart City & SDGs	intelligent transportation, digital infrastructure, sustainable urban mobility, and SDGs	Allam et al. (2022); Bibri (2022); Mohsen (2024); Bono et al. (2026)

Beyond environmental sustainability, Smart Parking Systems also generate significant operational and user-oriented benefits. The reviewed studies indicate that real-time parking information and intelligent reservation mechanisms reduce driver uncertainty, shorten parking search duration, and improve the utilization of available parking resources. These improvements enhance user experience while simultaneously increasing the

operational efficiency of parking facilities and urban transportation networks (Paidi et al., 2020; Floris et al., 2022; Li et al., 2023; Kumar et al., 2024).

From the perspective of Smart City development, Smart Parking Systems function as an integral element of Intelligent Transportation Systems (ITS) by facilitating data-driven transportation planning, digital infrastructure integration, and coordinated urban mobility management (Allam et al., 2022; Bibri, 2022; Mohsen, 2024). Furthermore, several recent studies emphasize that integrating IoT, Artificial Intelligence, cloud–edge computing, and Digital Twin technologies enables predictive traffic management, optimized resource allocation, and evidence-based policy development, thereby strengthening urban resilience and transportation sustainability (Verma et al., 2022; Tsai et al., 2025; Channamallu et al., 2026).

Overall, the synthesized evidence suggests that the contribution of Smart Parking Systems extends beyond improving parking efficiency. Their integration with emerging digital technologies supports broader sustainability objectives, including reduced carbon emissions, improved energy efficiency, enhanced urban mobility, and the achievement of the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) (Bibri, 2022; Sharma & Gupta, 2025; Bono et al., 2026).

3.5 Research Gap Analysis

The qualitative synthesis of the reviewed studies indicates that, despite significant advancements in IoT-based Smart Parking Systems, several important research gaps remain, as summarized in Table 3. These gaps reveal opportunities for future research aimed at developing more intelligent, interoperable, and sustainable parking management solutions.

Table 3. Research Gaps Identified from the Reviewed Studies

Research Area	Current Findings	Identified Gap	Future Research Opportunity
Technology Integration	Most studies focus on individual technologies (IoT, AI, communication)	Limited integrated Smart Parking architectures	Develop unified AioT - Cloud – Edge - Digital Twin frameworks
Sustainability Assessment	Emphasis on operational performance	Limited quantitative evaluation of GHG emissions, energy efficiency, and SDG impacts	Develop comprehensive sustainability assessment models
System Interoperability	Various IoT platforms and communication protocols	Lack of interoperability standards across heterogeneous devices	Design standardized and interoperable architectures
Cybersecurity & Privacy	Security issues acknowledged but rarely evaluated	Limited implementation of secure and privacy-preserving frameworks	Integrate blockchain, federated learning, and zero-trust security mechanisms
Emerging Technologies	Initial adoption of AIoT, Digital Twin, V2X	Limited real-world validation and scalability studies	Conduct large-scale field implementations and cross-city evaluations
Decision Support	Parking management focuses on operational efficiency	Limited integration with urban planning and policy decision support	Develop data-driven decision support systems for Smart Cities

First, most studies concentrate on individual technological components, such as IoT sensing devices, Artificial Intelligence, or wireless communication technologies, without comprehensively integrating these components into unified Smart Parking architectures. While individual technologies have demonstrated promising performance, relatively few studies propose holistic frameworks that combine intelligent sensing, AI-driven analytics, cloud–edge computing, and real-time decision support within a single interoperable ecosystem (Paidi et al., 2020; Biyik et al., 2021; Zulfiqar & Haque, 2023; Kumar et al., 2024).

Second, the reviewed literature remains predominantly technology-oriented, whereas comparatively limited attention has been given to evaluating the long-term environmental and socio-economic impacts of Smart Parking Systems. Most studies focus on improving parking occupancy detection and operational efficiency, while only a small number quantitatively assess carbon emission reduction, energy efficiency, traffic resilience, user behavior, or contributions to sustainable urban mobility and Smart City performance (Butler et al., 2020; Qin et al., 2021; Sharma & Gupta, 2025; Bono et al., 2026).

Third, practical implementation challenges continue to hinder large-scale deployment. Interoperability among heterogeneous IoT devices, communication reliability, cybersecurity, privacy protection, and data governance remain insufficiently addressed, particularly in complex urban environments where multiple stakeholders and legacy transportation infrastructures coexist (Silva et al., 2022; Verma et al., 2022; Alshahrani & Alotaibi, 2024). These issues emphasize the need for standardized architectures and secure communication frameworks capable of supporting scalable Smart Parking services.

Furthermore, several emerging technologies remain underexplored within Smart Parking applications. Although recent studies have introduced concepts such as AIoT, Digital Twin, federated learning, blockchain, and Vehicle-to-Everything (V2X) communication, their practical implementation is still limited and often validated only through simulations or small-scale case studies (Kumar et al., 2024; Tsai et al., 2025; Channamallu et al., 2026). Comprehensive evaluations involving real-world deployment, large-scale datasets, and cross-city implementations remain relatively scarce.

Overall, the identified research gaps indicate that future Smart Parking research should move beyond isolated technological innovation toward integrated, intelligent, and sustainability-oriented ecosystems. Future studies should prioritize interdisciplinary approaches that combine IoT sensing, Artificial Intelligence, cloud–edge computing, Digital Twin technologies, secure communication frameworks, and sustainability assessment models to support data-driven transportation planning and resilient Smart City development.

3.6 Future Research Directions

Based on the synthesized findings and the research gaps identified in this review, future studies should prioritize the development of intelligent, interoperable, and environmentally sustainable Smart Parking ecosystems. As summarized in Table 4, future research should move beyond isolated technological improvements toward integrated architectures that combine Internet of Things (IoT), Artificial Intelligence (AI), cloud–edge computing, Digital Twin, and Intelligent Transportation Systems (ITS). Such integration is expected to support predictive, adaptive, and autonomous parking management capable of responding to dynamic urban mobility demands.

Future research should also emphasize the development of standardized and interoperable Smart Parking platforms capable of supporting heterogeneous IoT devices, multi-vendor communication protocols, and seamless data exchange across Smart City infrastructures. Addressing interoperability, cybersecurity, privacy protection, and data

governance will be essential to ensure secure, reliable, and scalable deployment in real-world urban environments (Silva et al., 2022; Verma et al., 2022; Alshahrani & Alotaibi, 2024).

Another important research direction involves the broader adoption of emerging digital technologies. Although AIoT, Digital Twin, federated learning, blockchain, and Vehicle-to-Everything (V2X) communication have demonstrated significant potential, their implementation remains limited to conceptual frameworks, simulation studies, or small-scale pilot projects (Kumar et al., 2024; Tsai et al., 2025; Channamallu et al., 2026). Future investigations should therefore validate these technologies through large-scale field deployments, cross-city comparative studies, and real-world operational environments to evaluate their scalability, robustness, and practical effectiveness.

From a sustainability perspective, future evaluations should extend beyond operational performance by incorporating comprehensive sustainability indicators, including greenhouse gas (GHG) emission reduction, energy efficiency, transportation resilience, parking resource utilization, user satisfaction, and economic performance. Integrating these indicators into Smart Parking assessment frameworks will provide a more comprehensive understanding of their contribution to sustainable and low-emission urban mobility while supporting evidence-based transportation policy and decision-making (Butler et al., 2020; Sharma & Gupta, 2025; Bono et al., 2026).

Overall, the reviewed studies demonstrate that IoT-based Smart Parking Systems have evolved from conventional parking management solutions into essential components of next-generation Intelligent Transportation Systems and Smart Cities. Continued technological innovation, interdisciplinary collaboration, and real-world implementation will be critical to developing scalable, secure, intelligent, and sustainable Smart Parking solutions capable of addressing future urban mobility challenges while contributing to the achievement of the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

CONCLUSION

This study presented a Systematic Literature Review (SLR) of IoT-based Smart Parking Systems for sustainable and low-emission urban mobility by systematically synthesizing 50 selected studies published between 2020 and 2026 using the PRISMA 2020 framework. The review demonstrates that Smart Parking Systems have evolved from conventional parking occupancy monitoring solutions into intelligent, interconnected, and data-driven urban mobility platforms. Recent developments increasingly integrate Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), cloud–edge computing, AIoT, Digital Twin, and intelligent sensing technologies to enhance parking occupancy detection, traffic prediction, real-time decision-making, and integrated transportation management.

The synthesized evidence confirms that Smart Parking Systems contribute substantially to sustainable urban mobility by reducing parking search time, traffic congestion, fuel consumption, and greenhouse gas emissions while improving parking resource utilization and transportation efficiency. Beyond operational improvements, Smart Parking has become an important enabler of Smart Cities and Intelligent Transportation Systems (ITS), supporting data-driven transportation planning, digital infrastructure integration, and sustainable urban development. This review also provides a comprehensive classification of enabling technologies, identifies current research trends, and synthesizes the sustainability contributions reported across the reviewed studies.

Despite these advancements, several research gaps remain. Existing studies predominantly emphasize individual technological components rather than integrated Smart Parking ecosystems. In addition, interoperability among heterogeneous IoT devices, cybersecurity, data privacy, large-scale deployment, and standardized sustainability assessment frameworks remain significant challenges. Emerging technologies such as AIoT, Digital Twin, federated learning, blockchain, and Vehicle-to-Everything (V2X) communication have shown considerable potential but require further validation through real-world implementation and large-scale empirical studies.

Based on these findings, future research should focus on developing integrated, intelligent, and interoperable Smart Parking ecosystems that combine advanced digital technologies with comprehensive sustainability assessment models. Future investigations should incorporate environmental, economic, operational, and social performance indicators to better evaluate the long-term contribution of Smart Parking Systems to sustainable and low-emission urban mobility. Overall, this review provides a consolidated knowledge base and a future research agenda that can support researchers, practitioners, and policymakers in advancing next-generation Smart Parking Systems and accelerating the development of resilient, sustainable, and intelligent urban transportation.

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