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Original Article

Enabling Smart Home Sustainability with LoRaWAN: A Review of Energy and Water Sensing Technologies and Applications

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Abstract *- LoRaWAN is cost-efficient, provides long-range communication, and has low power consumption, making it an appropriate communication technology for the IoT-based energy and water sensing system. This review presents recent developments in LoRaWAN for domestic energy monitoring, water sensing, and integrated smart-home resource management. Research was conducted through thematic analysis of studies retrieved from extensive searches of major scientific databases between 2020 and 2026. LoRaWAN has been used for smart metering, water quality monitoring, irrigation systems and infrastructure monitoring. Many investigations have considered its energy efficiency, scalability and benefits in live data collection. Recently, investigations are increasingly applying communication optimization and AI-based approaches to enhance system adaptability and efficiency. The studies mostly focus on independent applications rather than integrated energy-water management systems. Scalability, communication dependability, and feasible execution remain challenging problems. This study examines the current trends, research gaps, and future prospects of intelligent, sustainable, and scalable smart-home sensing systems based on LoRaWAN technology.*

Keywords *- LoRaWAN, Internet of Things (IoT), Smart Home Systems, Energy and Water Monitoring, Sustainable Resource Utilization.*

1. Introduction

The need for environmentally sustainable resource management in residential settings has increased the demand for monitoring and control of energy and water systems. The management of household resources has become more complicated due to the increasing number of smart home devices, renewable energy sources, and changing consumption patterns. In this environment, IoT technologies allow for sophisticated monitoring systems. In particular, Low-Power Wide-Area Network (LPWAN) technologies, especially LoRaWAN, are studied for their extended-distance communication, low power consumption, and potential for large-scale sensing applications (Lalle et al. 2021). LoRaWAN has been shown to be a feasible solution for smart water grid surveillance and routing enhancement. Then, integrated metering systems were proposed for monitoring energy and water consumption (Sushma *et al.,* 2023). More studies (Lavdas *et al.,* 2025) have demonstrated the scalability and reliability of LoRaWAN for smart water metering and distributed sensing.

Consequently, the use of LoRaWAN for home energy monitoring systems has attracted increasing research attention. Energy efficiency, reduced communication overhead, and real-time data collection are among the motivations for several works proposing LoRaWAN-based smart metering and appliance-level monitoring systems (Kumari *et al.*, 2022; Sanchez-Sutil and Cano-Ortega, 2023; Al-Sammak *et al.*, 2025; Mante *et al.*, 2021; Enriko *et al.*, 2021). Furthermore, adaptive data rate mechanisms, energy-efficient transmission approaches, and machine learning-based optimization techniques have been studied (Jafari and Silva, 2025; Alvarado-Alcon *et al.*, 2025; Maudet *et al.*, 2026; Morales-Álvarez *et al.*, 2025) to enhance the system performance and reduce the energy consumption. LoRaWAN has also been applied to smart irrigation and automated agricultural systems, as well as to energy monitoring, demonstrating its versatility in resource management (Sánchez-Sutil and Cano-Ortega, 2021; Froiz-Míguez *et al.*, 2020). However, state-of-the-art research is based on single-resource systems, primarily energy, and does not consider integrated management solutions for multiple household resources. LoRaWAN is used in water-sensing applications such as tank monitoring, water quality testing, and monitoring of large distribution systems. Several studies (Abubeker and A. Nuthalapati, 2025; Jabbar *et al.*, 2024; Slaný *et al.*, 2020; Nuthalapati et al., 2024; Murti *et al.*, 2024; Syed Taha *et al.*, 2024; Chieu *et al.*, 2024; Liloja *et al.*, 2021) have demonstrated the advantages of real-time water monitoring by sensor networks and cloud platforms based on LoRaWAN for improving residential and urban water management. To address the issues related to large water distribution systems, pipeline monitoring and leak detection programs have been designed (Lin *et al.*, 2025; Pagano *et al.*, 2025a; Pagano *et al.*, 2025b; Boebel *et al.*, 2023). More recent research has integrated AI with IoT to improve the prediction and decision-making of water systems (Cai *et al.*, 2026; Faber *et al.*, 2026). These studies demonstrate the robustness and versatility of LoRaWAN in the water and energy sectors. However, they evaluate these systems separately, which limits their ability to address residential resource consumption.

Additional works have been dedicated to optimizing communication and device-level aspects, and application-specific studies to improve the effectiveness and efficiency of the system. Modeling of energy consumption, adaptive spreading factor allocation, and performance evaluation over deployment conditions (Soler-Fernández et al., 2026; Nisar *et al.*, 2025; Philip and Singh, 2023; Philip and Singh, 2024) have been considered to improve the system dependability and scalability. Hybrid communication architectures and deployment techniques are considered to address the problems of signal attenuation, interference, and environmental limitations (Cappelli *et al.*, 2022; Slany *et al.*, 2022; Sinagra *et al.*, 2025). LoRaWAN has been widely used across sectors, and many reviews highlight its usefulness in IoT systems, as well as its scalability, security, and performance challenges (Bonilla *et al.*, 2023). Energy and water monitoring is a common application for LoRaWAN, but only limited frameworks have been reported for integrated energy-water sensing in smart homes. Most current research focuses on individual systems rather than on the interactions and interdependencies between energy and water. In practical applications, the system performance is still constrained by indoor signal attenuation, data speed limitations and the requirement of adaptive communication techniques. Integrated frameworks for sensing, communication and intelligent optimization are required to overcome these limitations. This review of energy and water monitoring systems based on LoRaWAN provides an overview of current trends, challenges and the potential for integrated, sustainable smart home solutions.

The literature review publications are classified into four thematic categories based on the application domain and contributions to LoRaWAN-based sensing systems. The groups include: energy monitoring, water sensing, integrated energy-water applications, and communication and optimization methodologies. The applications, methods, and major contributions of the publications are summarized in Table 1.

Therefore, the objective of this review is to explore the use of LoRaWAN-based sensing technologies for residential energy and water management, to identify current trends and limitations, to assess the degree of integration between energy and water sensing systems, and to highlight research gaps and future opportunities for sustainable smart-home applications.

This review is distinct from existing reviews that cover LoRaWAN applications across various sectors in general or solely focus on singular energy or water applications in particular. This review, however, is focused on the intersection of LoRaWAN-enabled energy and water sensing in smart home environments. There is a limited integration of these two resource domains, communication and scalability challenges and the emerging role of AI and optimisation in enabling intelligent residential resource management are particularly highlighted. Thus, the review provides a focused basis for the development of integrated and sustainable sensing frameworks for smart homes.

2. Methods

In March-April 2026, a literature search was conducted in Google Scholar, IEEE Xplore, Scopus, and Web of Science for peer-reviewed articles on LoRaWAN applications in energy and water sensing systems. The search included studies between 2020 and 2026 to include the latest trends in IoT-based monitoring technology. Search terms were combinations of keywords, i.e., (“LoRaWAN” OR “LPWAN”) AND (“energy monitoring” OR “smart metering” OR “water monitoring” OR “water quality” OR “smart home” OR “IoT sensing systems”).

46 articles were included out of 65 papers. The water-sensing applications accounted for about 32% of the works, energy-monitoring systems 28%, communication-optimization strategies 24%, and integrated energy-water management systems only 16%. This distribution implies that unified resource management systems receive very little research attention.

The selected studies were categorized by theme to better understand the research environment. The categories are (i) energy monitoring systems, (ii) water sensing systems, (iii) integrated energy-water applications, and (iv) communication and optimization methodologies for improving the performance of LoRaWAN. Literature search, eligibility assessment of the retrieved articles, and the initial review were conducted by the main author (C.O.). The second author (J.E.) performed a thematic categorization of the selected papers. The consistency and correctness of topic categorization were assessed by the third author (C.U.). For extensive coverage of research in engineering, IoT, and smart systems, and for access to high-quality and relevant publications, the following databases were chosen: Google Scholar, IEEE Xplore, Scopus, and Web of Science. To reduce the selection bias, the articles were screened by title, abstract, and relevance to LoRaWAN-based sensing applications.

A limitation of this review is that the selection of databases may have omitted studies not included in these databases. Moreover, the review was limited to English publications only, which might result in the omission of studies from non-English-speaking countries. The review nonetheless offers a systematic overview of recent advances in energy and water monitoring systems based on LoRaWAN. Figure 1 shows the flowchart of the literature selection.

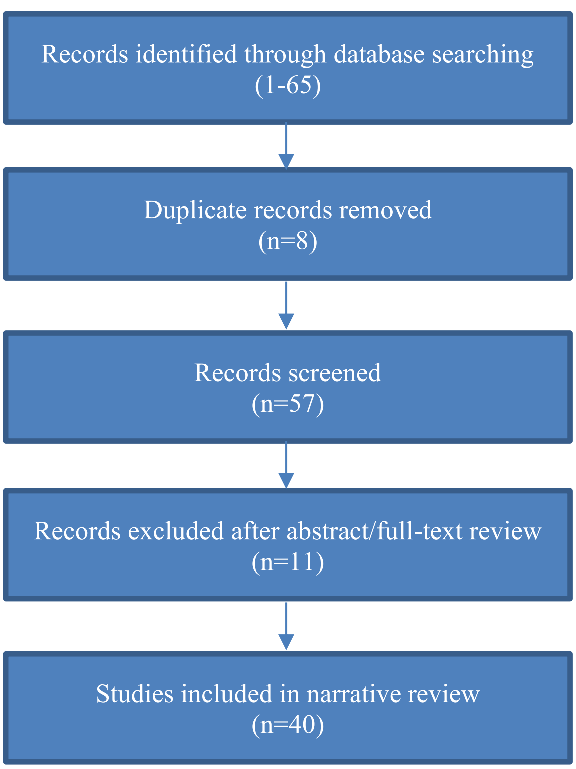

Fig. 1 Flowchart of the literature search and selection process

3. Results

In the literature review presented in this work, published works were categorized into four thematic groups based on their main application domains and contributions to LoRaWAN-based sensing systems. The categories include energy monitoring systems, water sensing systems, integrated energy-water applications, and communication and optimization methodologies. A complete summary of the surveyed works, including application domains, methodologies, and major contributions, is presented in Table 1.

3.1. Energy Monitoring Systems

LoRaWAN is widely adopted in the energy monitoring area, especially for smart metering and appliance-level sensing. Several researches have presented the use of LoRaWAN-based smart meters and smart plugs for instantaneous monitoring of electrical parameters, e.g., voltage, current, and power consumption (Kumari *et al.*, 2022; Sanchez-Sutil and Cano-Ortega, 2023; Mante *et al.*, 2021; Enriko *et al.*, 2021). The systems facilitate remote data acquisition and control, which in turn benefits energy efficiency and demand side management strategies. Furthermore, adaptive and optimization-based approaches have been proposed to improve system performance, such as reducing data transmission frequency while maintaining monitoring accuracy (Al-Sammak *et al.*, 2025).

Integration of edge processing with IoT platforms improves the system's responsiveness and expandability by enabling local data processing and reducing network overhead [4].

Smart lighting and distributed energy monitoring systems (Khairullah *et al.*, 2025; Pasetti *et al.*, 2020) demonstrate LoRaWAN's ability to enable energy-efficient operations in residential and semi-urban environments. Also, device-level optimization is explored, e.g., power modeling of LoRa transceivers, to gain insight into energy consumption and lifetime extension of IoT nodes (Soler-Fernández et al., 2026).

Unfortunately, most energy monitoring systems are still implemented as a stand-alone solution with a focus on power consumption, while interactions with other household resources are ignored. This hinders their efficiency in achieving optimal resource utilization in smart home environments.

LoRaWAN is a useful technology for smart metering applications, but most current research has focused on data collection and transmission efficiency instead of intelligent decision-making.

Rarely do you hear about adaptive optimization, predictive analytics and integrated resource coordination.

Evaluation of the performance in actual deployments is still limited, especially in dense areas, where signal degradation and network traffic can affect performance.

3.2. Water Sensing Systems

LoRaWAN is widely used for water sensing applications such as water level, water quality, and distribution systems. Several research studies present IoT-based systems for automatic water tank monitoring that efficiently control water consumption in the house and minimize wastage (Abubeker and A. Nuthalapati, 2025; Slaný *et al.*, 2020; Jabbar *et al.*, 2024; Nuthalapati et al., 2024; Murti *et al.*, 2024; Syed Taha *et al.*, 2024; Chieu *et al.*, 2024; Liloja *et al.*, 2021). LoRaWAN based systems have been developed to monitor water quality parameters such as pH, turbidity and temperature, providing real-time data to support better management of water.

Also, complete water-monitoring systems have been proposed for pipeline monitoring and leak detection, demonstrating the capability of LoRaWAN for long-range sensing in infrastructure systems (Lin *et al.*, 2025; Pagano *et al.*, 2025a; Pagano *et al.*, 2025b; Boebel *et al.*, 2023). Often, these systems are equipped with energy-harvesting technologies and low-power communication techniques for long-term operation with little or no maintenance.

Artificial intelligence techniques are integrated into water monitoring systems to enhance predictive functions and the early detection of irregularities, thereby improving system reliability (Cai *et al.*, 2026; Faber *et al.*, 2026).

However, as with energy systems, most water-sensing applications are developed in isolation, with little thought given to integration with energy monitoring systems. Such a disjointed approach makes it difficult to develop integrated smart home solutions that can solve many resource management problems at once.

3.3. Integrated Energy-Water Applications

Much of the literature concerns integrated energy-water sensing and management systems. This research demonstrates LoRaWAN's capacity to enable integrated monitoring systems that can support multiple household resources under a single communication framework. Proposed integrated smart metering systems feature energy and water monitoring capabilities to give a complete picture of domestic resource consumption (Sushma *et al.,* 2023).

Furthermore, optimization-based approaches have been used to enhance the energy performance and communication performance of these systems, showing the advantages of coordinated resource management (Al-Sammak *et al.*, 2025).

The interdependence between energy and water resources is exemplified in irrigation systems, where water efficiency is strongly related to energy consumption for pumping and distribution operations (Sánchez-Sutil and Cano-Ortega, 2021; Froiz-Míguez *et al.*, 2020; Liopa-Tsakalidi et al., 2024).

However, the volume of research on integrated energy-water systems is limited. Most current research focuses on specific use cases rather than on developing generic frameworks for integrated resource management. It reveals a significant research gap and the need for extensible, intelligent systems capable of processing networked resources in real time.

3.4. Communication and Optimization Techniques

A large number of works are dedicated to improving the performance, scalability and energy efficiency of LoRaWAN-based systems through the use of communication and optimization techniques.

Adaptive data rate mechanisms, energy consumption models, and parameter refinement techniques to improve network performance and reduce energy consumption have been studied in several research works (Jafari and Silva, 2025; Alvarado-Alcon *et al.*, 2025; Maudet *et al.*, 2026; Morales-Álvarez *et al.*, 2025; Nisar *et al.*, 2025; Philip and Singh, 2023; Philip and Singh, 2024). These techniques are required to provide reliable connectivity for large-scale and dense IoT deployments.

A device-level optimization study based on parametric power modeling of LoRa transceivers yields useful insights into the trade-offs between signal reliability and energy efficiency (Soler-Fernández et al., 2026).

Moreover, hybrid communication architectures have been proposed to overcome the issues of signal degradation and interference, especially in indoor and metropolitan environments (Cappelli *et al.*, 2022; Slany *et al.*, 2022; Sinagra *et al.*, 2025). These techniques improve the robustness of the system and increase the applicability of LoRaWAN to several deployment scenarios.

Furthermore, research studies offer a holistic picture of LoRaWAN implementation across the domains, emphasizing major issues such as scalability, security and network management (Bonilla *et al.*, 2023). These works highlight the importance of integrating optimization techniques into sensing applications to achieve efficient, reliable system performance.

Table 1 shows the classification of energy and water sensing studies based on LoRaWAN, while Table 2 presents a summary of study gaps in existing LoRaWAN smart house studies. The review also included a distribution of the reviewed articles by study area (see Figure 2).

Table 1. Classification of LoRaWAN-Based Energy and Water Sensing Studies

Ref	Domain	Application	Methodology	Key Contribution
(Lalle et al. 2021)	Water	Leak detection	Routing + SDN	Network efficiency
(Sushma et al., 2023)	Energy-Water	Smart metering	IoT + LoRaWAN	Integrated monitoring system
(Lavdas et al., 2025)	Water	Smart metering	Performance analysis	Large-scale deployment insights
(Kumari et al., 2022)	Energy	Smart metering	Edge + DL	Efficient data transmission
(Jafari and Silva (2025))	Communication	IoT survey	Analysis	Constraints in low-power systems
(Alvarado-Alcon et al., 2025)	Communication	Optimization	ML	Reduced carbon footprint
(Abubeker and A. Nuthalapati (2025))	Water	Tank monitoring	IoT + LoRaWAN	Automated water control
(Maudet et al., 2026)	Communication	Protocol comparison	Modeling	LoRaWAN vs Wi-Fi HaLow
(Jabbar et al., 2024)	Water	Quality monitoring	IoT sensor	Accurate sensing
(Cappelli et al., 2022)	Water	Underwater sensing	Experimental	Extended LoRaWAN capability
(Lin et al., 2025)	Water	Pipeline monitoring	Simulation	Underground communication
(Slany et al., 2022)	Hybrid	Communication	Hybrid IoT	Improved connectivity
(Sanchez-Sutil and Cano-Ortega (2023))	Energy	Smart plug	IoT + LoRaWAN	Appliance monitoring
(Sinagra et al., 2025)	Water	Distribution systems	Energy harvesting	Self-powered sensing
(Pagano et al., 2025a)	Water	WDS monitoring	IoT framework	Leak detection optimization
(Pagano et al., 2025b)	Water	Survey	IoT + EC	Large-scale insights
(Philip and Singh (2022))	Water	Quality monitoring	Optimization	Energy efficiency
(Cai et al., 2026; Faber et al., 2026)	Water	Treatment systems	AI + IoT	Predictive monitoring
(Faber et al., 2026)	Water	Monitoring	AI + LoRaWAN	Predictive analytics
(Jabbar et al., 2025)	Energy	Smart lighting	IoT + LoRaWAN	Energy savings
(Morales-Álvarez et al., 2025)	Communication	ADR optimization	Modeling	Improved efficiency
(Al-Sammak et al., 2025)	Energy	Smart metering	Adaptive algorithm	Reduced energy waste
(Sánchez-Sutil and Cano-Ortega (2021))	Water	Irrigation	IoT + LoRaWAN	Resource optimization
(Froiz-Míguez et al., 2020)	Water	Irrigation	Fog + IoT	Reduced water consumption
(Pagano et al., 2025)	Water	Pipeline sensing	Energy harvesting	Autonomous devices
(Nisar et al., 2025)	Communication	Optimization	ML	Efficient SF allocation
(Khairullah et al., 2025)	Water	Review	LoRaWAN	System challenges
(Slaný et al., 2020)	Water	Smart metering	IoT	Real-time monitoring
(Nuthalapati et al., 2024)	Water	Quality monitoring	IoT	Reliable sensing
(Murti et al., 2024)	Water	Quality monitoring	IoT	Real-time sensing
(Syed Taha et al., 2024)	Water	Performance	LoRaWAN	Deployment insights
(Jabbar et al., 2022)	Energy	PV monitoring	IoT	Remote sensing
(Pasetti et al., 2020)	Energy	Smart campus	IoT	Distributed monitoring
(Soler-Fernández et al., 2026)	Communication/Energy Efficiency	LoRaWAN device power modeling	Experimental + parametric modeling	Accurate power consumption model for LoRa transceivers

				enabling energy-efficient IoT system design
(Mante et al., 2021)	Energy	Monitoring	IoT	Real-time tracking
(Enriko et al., 2021)	Energy	Smart meter	IoT	Rural deployment
(Liopa-Tsakalidi et al., 2024)	Energy-water	Irrigation	IoT	Resource optimization
(Philip and Singh (2023))	Communication	Efficiency	Modeling	Improved performance
(Philip and Singh (2024))	Communication	Efficiency	Modeling	Low-power optimization
(Devika et al., 2022)	Infrastructure	Monitoring	IoT	Scalable sensing
(Valente et al., 2022)	Communication	Optimization	Adaptive	Improved reliability
(Yin et al., 2023)	Energy	Smart building	IoT	Energy management
(Chieu et al., 2024)	Water	Quality monitoring	IoT	Reliable sensing
(Liloja et al., 2021)	Communication	Optimization	Modeling	Enhanced scalability
(Bonilla et al., 2023)	General/Review	LoRaWAN applications (multi-domain)	Systematic literature review	Comprehensive overview of LoRaWAN applications, devices, and challenges across domains

Table 2. Research Gaps in Existing LoRaWAN Smart Home Studies

Specialization	Focus	Bottleneck	Future Requirement
Energy Monitoring	Smart metering	Standalone systems	Integrated frameworks
Water Monitoring	Quality sensing	Limited AI integration	Predictive analytics
Communication	ADR optimization	Indoor attenuation	Hybrid architectures
AI Applications	Prediction	Limited real deployment	Adaptive control
Smart Homes	Monitoring	No unified optimization	Energy-water coupling

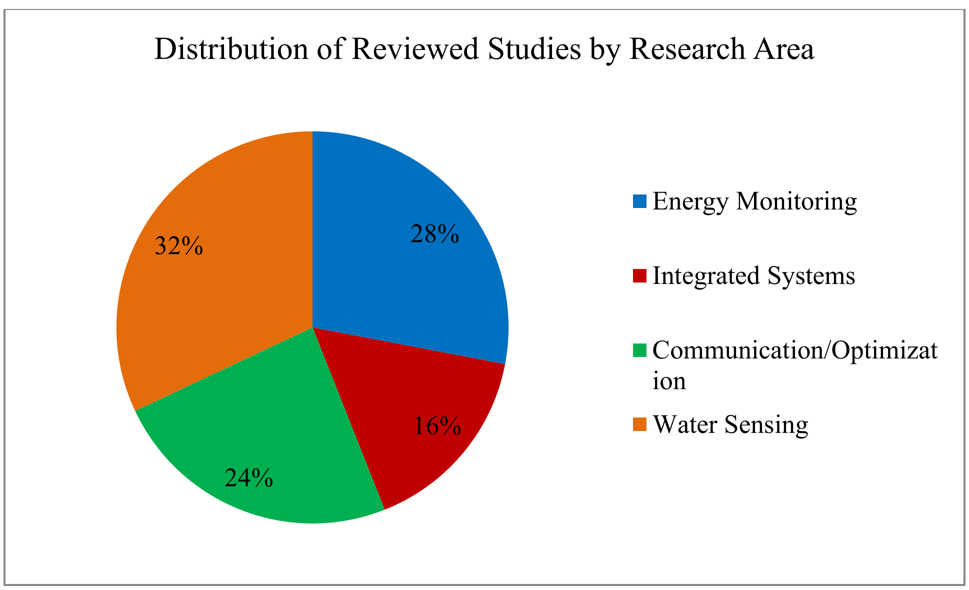

Fig. 2 Distribution of reviewed studies by research area

The distribution of the studies reviewed shows a clear imbalance in the research focus. Water sensing applications comprise the largest segment (32%), followed by energy monitoring (28%) and communication and optimisation studies (24%), whereas integrated energy-water applications are only 16%. The distribution suggests that while LoRaWAN has been extensively investigated for individual resource monitoring, coordinated residential energy–water sensing has been largely overlooked. So, the relatively small percentage of integrated studies is an important research opportunity for developing unified smart-home resource management systems.

4. Discussion

This review examines the growing adoption of LoRaWAN as a communication infrastructure for IoT-based sensing devices, especially for energy and water monitoring. The studies concluded that LoRaWAN is ideal for residential and distributed sensing applications because of its low power consumption, long-range connectivity, and cost-effectiveness. Rather than showing better performance with a new experimental implementation, this review highlights the merits and demerits of the already developed approaches within the framework of integrated residential energy-water management. These characteristics allow expandable energy and water monitoring systems, as demonstrated in Table 1. However, these benefits of LoRaWAN implementation are domain-specific, and most research focuses on energy or water systems. This separation prevents you from solving smart-home resource-consumption problems, because water and energy consumption overlap. The literature distinguishes system-level integration and application development. Although many studies have proposed effective sensing and monitoring systems, few have addressed the need for integrated frameworks to manage multiple resources. The present approaches are often application-specific and rarely study integrated energy-water systems. This mismatch underscores the need for integrated sensing, communication, and intelligent control systems. Many studies use optimization and AI to improve the system efficiency, but they neglect cross-domain connectivity and real-time flexibility in dynamic environments. This review focuses on optimizing system performance at the communication and device levels. The network efficiency and device lifetime are improved through adaptive data rate regulation, spreading factor optimization, and energy consumption modeling. However, these methods require careful tuning in the context of trade-offs among dependability, latency and energy utilization. Indoors, these systems still suffer from signal weakening, interference in populated areas and limited data rates, which make them difficult for wide adoption, especially in urban residential areas. LoRaWAN-based sensing systems can be improved by Artificial Intelligence and data-based methods. The system intelligence can be integrated with AI-enabled predictive analytics and adaptive control to enable immediate decision-making and preemptive resource management. These are new approaches with little practical application and validation. The issues of data availability, model generalization and processor restrictions in low-power devices need to be addressed to fully leverage AI-based systems.

The study identifies some key directions for future research. These include integrated energy-water management systems, hybrid AI-optimization approaches for real-time decision making, and scalable frameworks that perform well under resource-constrained conditions. Further observational confirmation and pragmatic application are needed to bridge the divide between theoretical models and applied scenarios. The challenges need to be addressed to unlock the complete potential of LoRaWAN in supporting sustainable and intelligent smart home systems.

Energy sensing applications are more mature than water sensing applications, given the deployment of smart metering infrastructure. AI - based anomaly detection and predictive maintenance through water sensing systems. Integration systems are still immature, but could allow coordinated sustainability optimization.

The results show that among the integrated energy-water studies, LoRaWAN research has the lowest share, which indicates a major research gap, even in the context of the aims of smart home sustainability.

4.1. Ethical and Privacy Concerns

The deployment of LoRaWAN-powered sensing systems in residential settings also raises some important ethical considerations. The use of household energy, water consumption, occupancy and environmental data can reveal sensitive information about the routines and behaviour patterns of occupants. Therefore, the future implementations should consider the practices of informed consent, minimisation of the data, secure transmission, controlled access and adequate anonymisation or pseudonymization. Moreover, the application of artificial intelligence for prediction and automated decision-making should consider potential biases due to datasets that might not adequately represent different types of households, socioeconomic status or behaviours of the user. These considerations are particularly important in the development of smart-home systems that are not only technically effective, but also trustworthy, inclusive and socially responsible.

5. Conclusion

This article discusses LoRaWAN-based sensor systems for energy and water management, and their growing importance in smart home and IoT applications. The results show that LoRaWAN is an efficient alternative for low-power, long-range communications for resource monitoring, but current implementations are single-domain applications with little integration with energy and water systems. The review determines that communication optimization, energy-efficient device design, and AI-driven approaches have enhanced the system’s performance, scalability, and adaptability. However, problems with system architecture, empirical validation, communication reliability, and data management are not satisfactorily addressed. Such limitations call for the need of integrated sensing, communication and intelligent control frameworks for resource management. Future research should focus on scalable, AI-based, application-oriented solutions that perform well in the real world, especially in resource-constrained environments. LoRaWAN can potentially deliver sustainable, efficient and intelligent energy-water management systems for smart homes and beyond. Future research should focus on real-world deployment of AI-enabled integrated energy-water frameworks for adaptive decision-making in resource-constrained smart houses.

Author Contributions

Conceptualization, Chisom Ogbuanya. and Joy Eneh.; methodology, Chisom Ogbuanya.; software, Chisom Ogbuanya.; validation, Collins Udanor and Ozoemena Ani.; formal analysis, Chisom Ogbuanya.; investigation, Joy Eneh.; resources, Chisom Ogbuanya.; data curation, Chisom Ogbuanya.; writing—original draft preparation, Chisom Ogbuanya.; writing—review and editing, Joy Eneh.; visualization, Joy Eneh, and Collins Udanor.; supervision, Collins Udanor.; project administration, Ozoeman Ani.; funding acquisition, Chisom Ogbuanya.

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