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IoT Solutions for Energy Efficiency: A Bibliometric Analysis of Environmental Impact and Resource Management

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ABSTRACT

This bibliometric analysis explores the scope and dynamics of Internet of Things (IoT) research with a focus on energy efficiency, environmental impact, and resource management. Using data sourced from Scopus and visualized through VOSviewer, the study maps out the evolution of research themes, highlights interdisciplinary collaboration, and discusses the integration challenges and policy implications of IoT technologies. The analysis identifies a significant shift from foundational technological issues to applications that enhance sustainable development and address global energy demands. Despite challenges such as implementation costs, security concerns, and environmental impacts associated with IoT devices, the potential of IoT in promoting energy efficiency and sustainability is profound. The study also emphasizes the need for robust policies and international cooperation to fully leverage IoT benefits in addressing environmental and energy management challenges. Future research directions are suggested to further explore the integration of IoT with renewable energy sources and to enhance the sustainability of IoT systems.

Keywords: *Internet of Things (IoT), Energy Efficiency, Sustainable Development, IoT Security, Bibliometric Analysis*

1. INTRODUCTION

The integration of the Internet of Things (IoT) into energy systems represents a significant leap towards enhancing energy efficiency and resource management. As global energy demands continue to rise, the urgency for sustainable solutions becomes more apparent. IoT technologies, with their ability to connect, analyze, and automate across various devices and sensors, offer potential paths to optimize energy use and minimize environmental impacts. This integration facilitates the real-time monitoring and management of energy consumption in industries, buildings, and even smart grids, promoting a more efficient energy landscape [1].

Moreover, the environmental implications of energy consumption and resource depletion are critical areas of concern that necessitate immediate attention. The capability of IoT solutions to provide detailed data and predictive insights can significantly contribute to more sustainable environmental practices. These technologies not only help reduce the carbon footprint by optimizing energy use but also assist in managing resources more effectively, thus promoting a balance between technological advancement and environmental conservation [2].

Research into IoT applications in energy efficiency has seen substantial growth, indicating a robust interest and investment in this area. Studies typically focus on how IoT technologies can reduce energy wastage and improve operational efficiencies. For instance, IoT devices can automatically adjust lighting and heating based on occupancy or external weather conditions, significantly reducing unnecessary energy consumption [3]. However, despite the promising advancements, the penetration of IoT solutions in energy management systems is uneven across different regions and industries. Various factors, including technology acceptance, infrastructure readiness, and economic viability, influence the adoption rates of IoT systems. These factors are crucial in understanding the broader implications and potential barriers to implementing IoT solutions effectively [4].

While the potential of IoT solutions in enhancing energy efficiency and managing resources is widely acknowledged, comprehensive insights into their environmental impacts are less understood. Most existing studies focus on the technical implementation and economic benefits, often overlooking the broader environmental implications such as e-waste, lifecycle impacts, and the carbon footprint of IoT devices themselves. There is a need for a systematic bibliometric analysis to synthesize existing research and identify gaps in the literature on the environmental impacts and resource management capabilities of IoT solutions in the context of energy efficiency [4].

This study aims to conduct a comprehensive bibliometric analysis to map the existing academic and industrial landscape concerning IoT solutions for energy efficiency, focusing particularly on their environmental impacts and resource management aspects. By analyzing trends, collaboration networks, and thematic concentrations within the corpus of literature, the study intends to uncover prevailing research directions, underexplored areas, and potential future trajectories. This analysis will provide stakeholders with a clear view of the field's evolution, highlighting significant contributions and emerging trends that could shape future research and implementation strategies.

2. LITERATURE REVIEW

2.1 *The Role of IoT in Energy Efficiency*

The application of Internet of Things (IoT) technologies in energy management systems (EMS) has been transformative, offering extensive capabilities for enhancing energy efficiency. IoT devices and sensors provide critical data that allow for the monitoring, controlling, and optimization of energy usage in real-time. For example, smart thermostats and lighting systems adjust settings based on real-time data, such as occupancy or ambient conditions, leading to significant reductions in energy consumption [5]. Furthermore, IoT-based smart grids support the integration of renewable energy sources into the power grid, facilitating more efficient energy distribution and consumption [6].

2.2 *IoT and Resource Management*

In addition to improving energy efficiency, IoT technologies play a crucial role in resource management. Smart meters and sensors can detect inefficiencies and losses in water, electricity, and gas supply systems, prompting timely interventions. For instance, IoT applications in water management include leak detection systems that prevent significant resource loss and reduce unnecessary consumption. Similarly, IoT solutions in waste management optimize collection routes and schedules based on real-time fill-level data from bins and dumpsters, enhancing operational efficiencies [7].

2.3 *Environmental Impact of IoT Solutions*

While IoT solutions offer numerous benefits for energy efficiency and resource management, they also have environmental implications that require careful consideration. The production, usage, and disposal of IoT devices generate significant amounts of electronic waste (e-waste), which pose challenges in waste management and recycling efforts. Additionally, the energy consumption of maintaining a vast network of interconnected IoT devices can offset some of the gains made by these technologies in reducing overall energy use [8], [9].

2.4 Integration Challenges and Technological Barriers

Despite the advantages, the integration of IoT technologies faces several challenges. One major barrier is the initial cost and complexity of setting up IoT systems, which can be prohibitive for small and medium enterprises (SMEs) and in developing countries. Moreover, concerns regarding data privacy and security continue to be significant hurdles, as the increase in data flow heightens the risk of breaches and cyber-attacks [10].

2.5 Adoption Rates and Economic Viability

The economic viability of IoT solutions is influenced by several factors, including the cost of technology, the regulatory environment, and the potential return on investment (ROI). Studies have shown that while the upfront costs are high, the long-term savings and benefits often justify the investment. Additionally, government incentives and subsidies can play a critical role in enhancing the economic viability of IoT solutions for energy efficiency [6].

2.6 Global Trends in IoT Adoption

Globally, the adoption of IoT technologies varies significantly. In developed countries, there is a faster adoption rate due to better infrastructure, higher technological literacy, and greater availability of financial resources. Conversely, in developing regions, the adoption is slower, often hindered by limited infrastructure and financial constraints. However, the potential for IoT to address critical issues such as energy efficiency and resource management makes it a vital technology for sustainable development worldwide [3].

3. METHODS

This study employs a bibliometric analysis focused solely on articles sourced from the Scopus database to examine the domain of IoT solutions for energy efficiency, specifically assessing their environmental impacts and resource management capabilities. The search was conducted for publications between 2010 and 2024, using keywords including "Internet of Things," "IoT," "energy efficiency," "environmental impact," and "resource management." The retrieved records were then exported to VOSviewer for bibliometric analysis, where we created visualization maps to highlight co-authorship networks and thematic trends. This software also facilitated the identification of the most cited articles, enabling a deeper analysis of prevailing theories and methodologies in the field.

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis

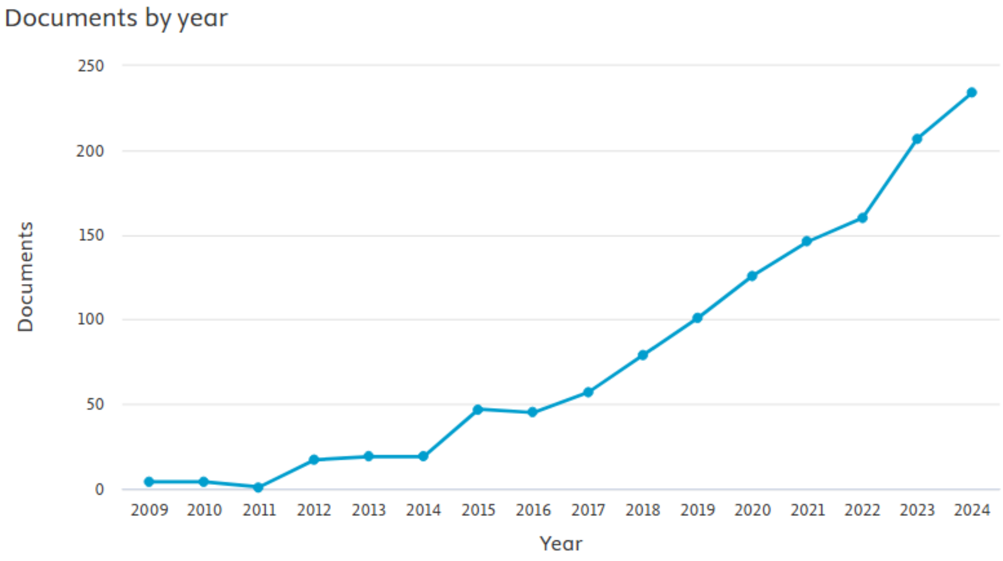

Figure 1. Documents by Year
Source: Scopus, 2024

The graph depicts a clear upward trend in the number of documents published on the topic of IoT solutions for energy efficiency from 2009 to 2024. Starting from fewer than 25 documents in 2009, there has been a gradual increase each year, reaching close to 250 documents by 2024. This steady rise illustrates a growing academic and industrial interest in researching the integration of IoT technologies with energy efficiency solutions. The accelerated growth in publications from around 2017 onwards suggests that significant advancements and innovations in IoT technologies, possibly due to improved IoT infrastructures and heightened awareness of energy sustainability issues, have sparked an increased research focus. The data from 2024 indicates a continuation of this trend, pointing to an ongoing commitment within the research community to explore and develop IoT applications that enhance energy efficiency and resource management.

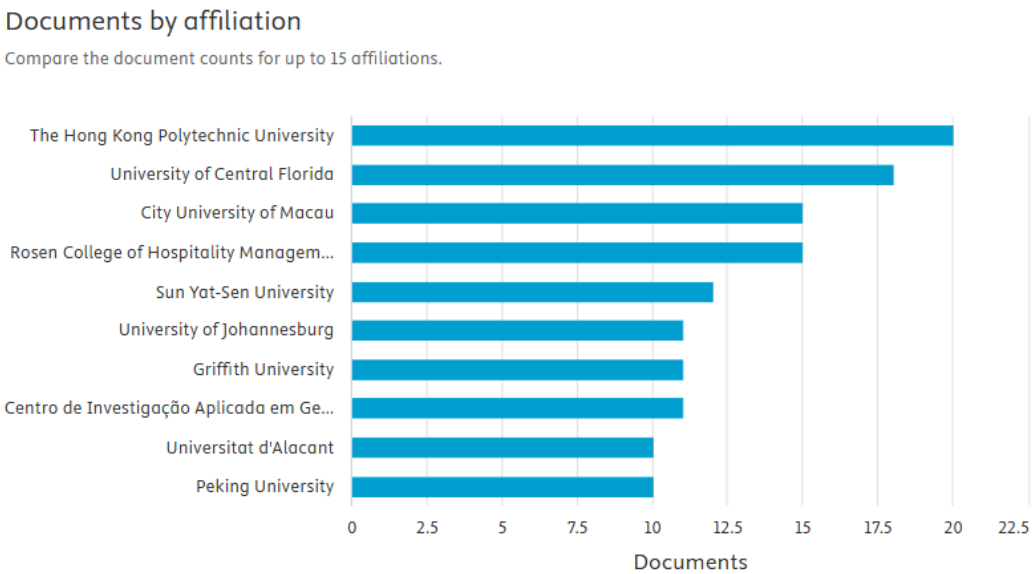

Figure 2. Documents by Affiliation
Source: Scopus, 2024

The bar chart illustrates the number of documents published by various institutions on the topic of IoT solutions for energy efficiency, identifying The Hong Kong Polytechnic University as the leading contributor with approximately 22 documents. This is followed by the University of Central Florida and City University of Macau, each contributing around 12 and 10 documents respectively. Other notable institutions include Rosen College of Hospitality Management, Sun Yat-Sen University, and the University of Johannesburg, each producing between 7 to 9 documents. Institutions like Griffith University, Centro de Investigação Aplicada em Gestão, Universitat d'Alacant, and Peking University also show engagement in the field, albeit with fewer contributions, ranging from about 2 to 6 documents each. This distribution highlights a diverse geographic spread in research activity related to IoT in energy efficiency, with significant contributions coming from both Western and Asian institutions, reflecting the global interest and collaborative nature of research in this technologically evolving field.

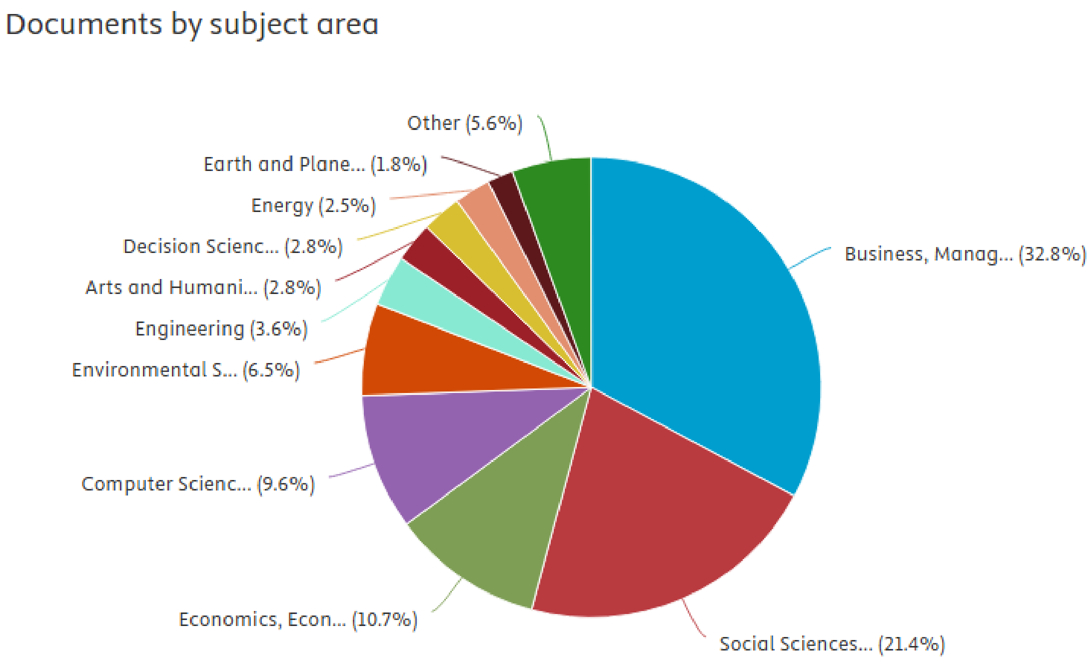

Figure 3. Documents by Subject Area
Source: Scopus, 2024

The pie chart presents the distribution of documents by subject area concerning IoT solutions, indicating a diverse interdisciplinary interest. Business and Management leads the research contributions with 32.8%, reflecting the significant interest in exploring IoT's applications within corporate strategies and operational efficiencies. This is followed by the Social Sciences, which accounts for 21.4% of the documents, suggesting a strong focus on the societal impacts and policy implications of IoT technologies. Economics, Econometrics, and Finance also make up a substantial portion at 10.7%, highlighting the economic considerations and potential financial benefits of IoT implementation. Computer Science represents 9.6% of the documents, underscoring the technical development and innovation within IoT systems. Other significant contributions include Environmental Science (6.5%), Engineering (3.6%), and smaller percentages in areas like Decision Sciences, Arts and Humanities, Energy, and Earth and Planetary Sciences. This variety in subject areas showcases the broad applications and implications of IoT across different fields, emphasizing its role in technological, economic, social, and environmental contexts.

4.2 Network Visualization

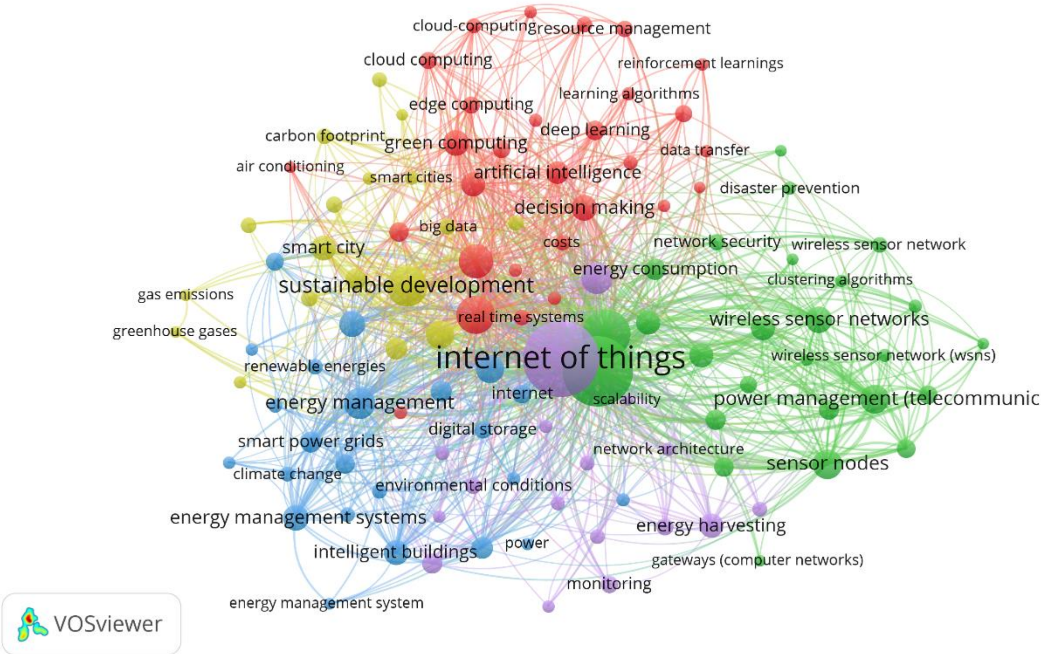

Figure 4. Network Visualization
Source: Data Analysis Result, 2024

This VOSviewer visualization represents a bibliometric network of key terms related to the study of IoT solutions, highlighting their intersections with various domains like energy management, sustainability, and computational technologies. The largest and most central node, "Internet of Things," directly connects to diverse thematic clusters, signifying the IoT's foundational role in linking various research areas. The green cluster closely associates IoT with "energy management," "smart power grids," and "renewable energies," emphasizing the technology's impact on optimizing energy use and integrating sustainable energy sources into the grid.

Adjacent to this, the red cluster focuses on computational technologies such as "cloud computing," "deep learning," and "artificial intelligence." These terms are interconnected with IoT, illustrating how advancements in AI and cloud technologies are crucial for processing and analyzing the vast amounts of data generated by IoT devices. This relationship is vital for developing smarter, more efficient systems that can autonomously adjust to changes in environmental conditions or user behaviors. The yellow cluster highlights terms like "sustainable development" and "smart cities," which connect with both the green and red clusters. This indicates a strong research focus on how IoT can contribute to broader sustainability goals through applications in urban planning and infrastructure. Keywords such as "carbon footprint" and "greenhouse gases" in this cluster underscore the environmental considerations that are increasingly prominent in studies of IoT implementations in urban settings.

Lastly, the green cluster sheds light on operational aspects of IoT, including "sensor nodes," "network security," and "wireless sensor networks." This cluster suggests a technical focus on the architecture and security challenges inherent in deploying IoT systems, which are critical for ensuring the reliability and safety of IoT solutions in energy management and other applications. Each of these clusters, while distinct, demonstrates the multidisciplinary nature of IoT research and its critical role in driving innovations across technological, environmental, and societal domains.

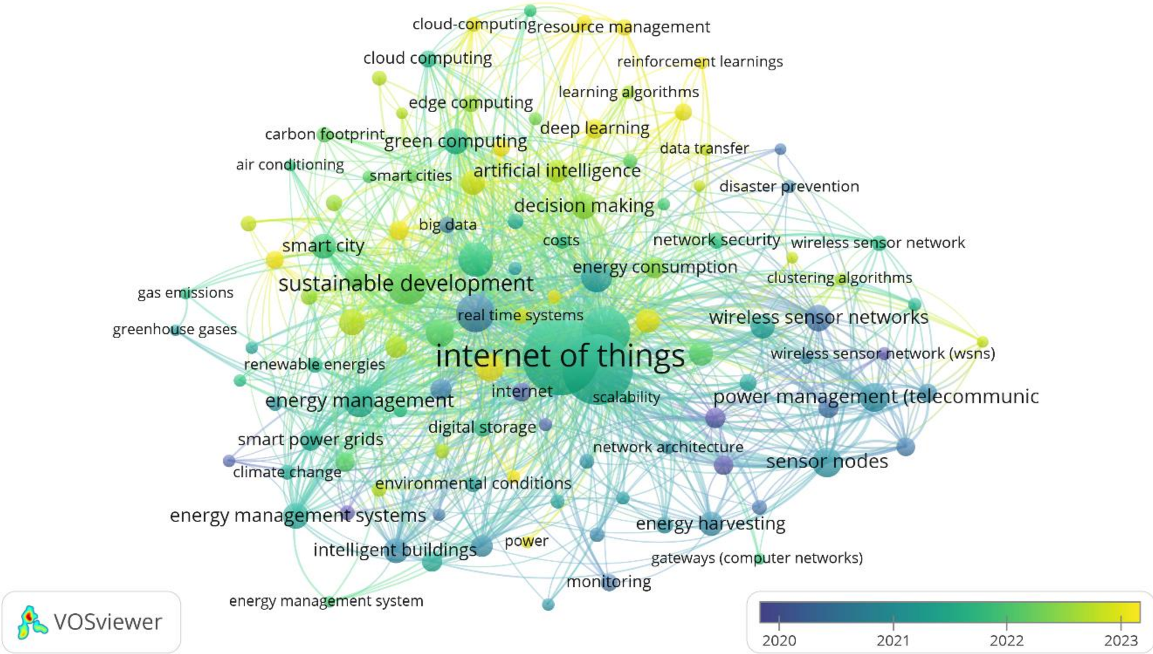

Figure 5. Overlay Visualization

Source: Data Analysis Result, 2024

The VOSviewer visualization with a temporal overlay from 2020 to 2023 illustrates the evolving focus of research in the IoT domain, highlighting the dynamic interplay between technology and sustainability. As indicated by the color gradient, there has been a clear shift over these years towards integrating IoT with systems addressing sustainable development and environmental management. The cluster around "Internet of Things," central in earlier years, remains vibrant, emphasizing its continued relevance in driving research across various applications.

By 2023, newer connections and keywords such as "energy harvesting," "energy management systems," and "intelligent buildings" emerge in lighter shades, indicating recent research interests. These terms suggest a growing focus on optimizing IoT to enhance energy efficiency within smart infrastructures and through renewable energy integrations. This shift aligns with global priorities for reducing carbon footprints and improving energy sustainability, reflecting an acute awareness of the environmental impacts of technology and the necessity for greener solutions in IoT deployments.

Moreover, the visualization highlights a sustained interest in areas like "cloud computing," "artificial intelligence," and "big data," which are crucial for the backbone of IoT functionality. The ongoing development and refinement in these areas, seen through their persistent presence across the timeline, underscore the critical role of advanced computational technologies in processing and managing the large volumes of data generated by IoT devices. This integration is key to unlocking the potential of IoT in real-time decision-making and predictive analytics, essential for smart cities and sustainable development initiatives.

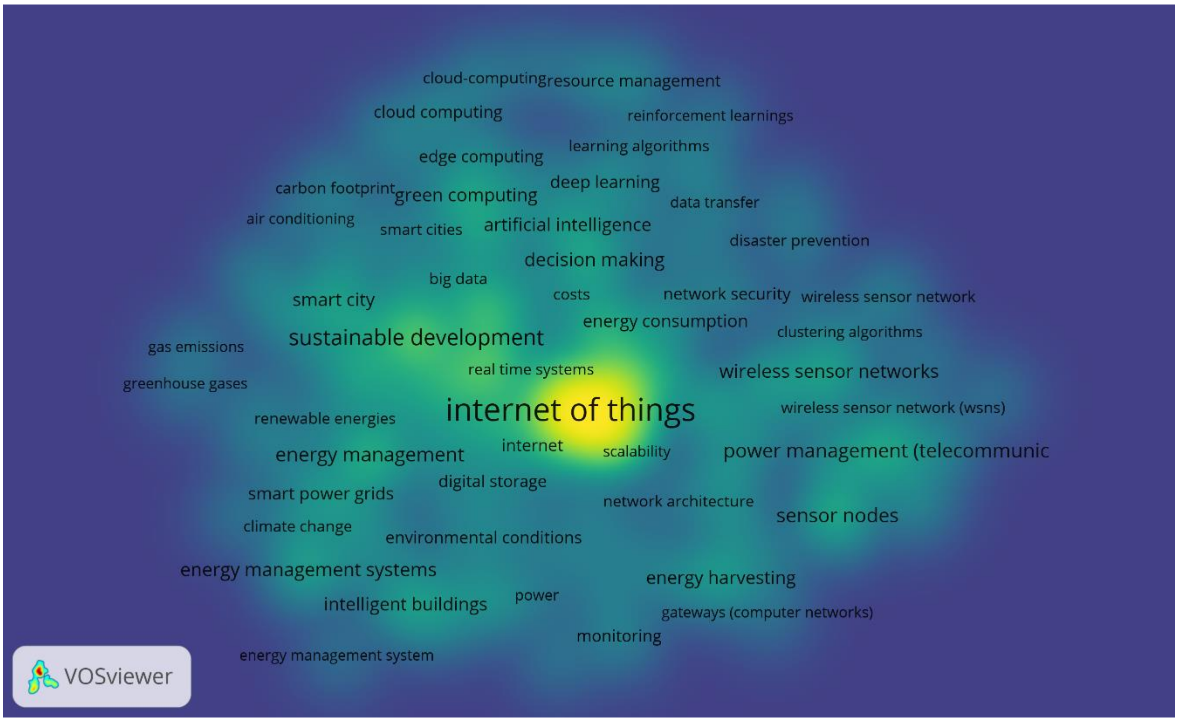

Figure 6. Density Visualization
Source: Data Analysis Result, 2024

The VOSviewer visualization maps a dense network of keywords in the field of IoT, underscoring the multifaceted nature of research that spans technology, environment, and energy management. Central to this map is the "Internet of Things," acting as a nexus connecting various sub-themes such as "energy management," "smart power grids," and "renewable energies," which are essential components for the advancement of smart and sustainable systems. The positioning of "sustainable development" alongside these terms reflects the growing focus on integrating IoT with sustainable practices. This integration aims to enhance the efficiency and sustainability of energy systems, making significant strides in reducing carbon footprints and greenhouse gas emissions through smarter energy solutions.

The surrounding clusters reveal a robust connection between IoT and advanced computing technologies, including "cloud computing," "edge computing," and "big data." These technologies are crucial for supporting the vast data requirements of IoT systems, enabling real-time processing and analytics necessary for optimizing operations and energy usage in smart environments. Furthermore, the presence of keywords like "network security" and "wireless sensor network" indicates a significant emphasis on ensuring the security and reliability of IoT networks. These aspects are vital for maintaining the integrity and performance of IoT systems, especially in applications that require high levels of data sensitivity and uptime, such as in smart cities and industrial IoT setups. This visualization illustrates the interconnectivity of technical and environmental considerations in IoT research, highlighting the dynamic evolution of this field towards more integrated and sustainable solutions.

4.3 Citation Analysis

Table 1. The Most Impactful Literatures

Citations	Authors and year	Title
527	[11]	The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability

Citations	Authors and year	Title
525	[12]	Blockchain for the future of sustainable supply chain management in Industry 4.0
293	[13]	Survey on collaborative smart drones and internet of things for improving smartness of smart cities
248	[14]	Adaptive configuration of lora networks for dense IoT deployments
200	[15]	A Review of Deep Reinforcement Learning for Smart Building Energy Management
196	[16]	Design architectures for energy harvesting in the Internet of Things
181	[17]	A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends
170	[18]	Maximization of wireless sensor network lifetime using solar energy harvesting for smart agriculture monitoring
169	[19]	I-SEP: An Improved Routing Protocol for Heterogeneous WSN for IoT-Based Environmental Monitoring
167	[20]	Energy harvesting towards self-powered iot devices

Source: Publish or Perish Output, 2024

4.4 Co-Authorship Network

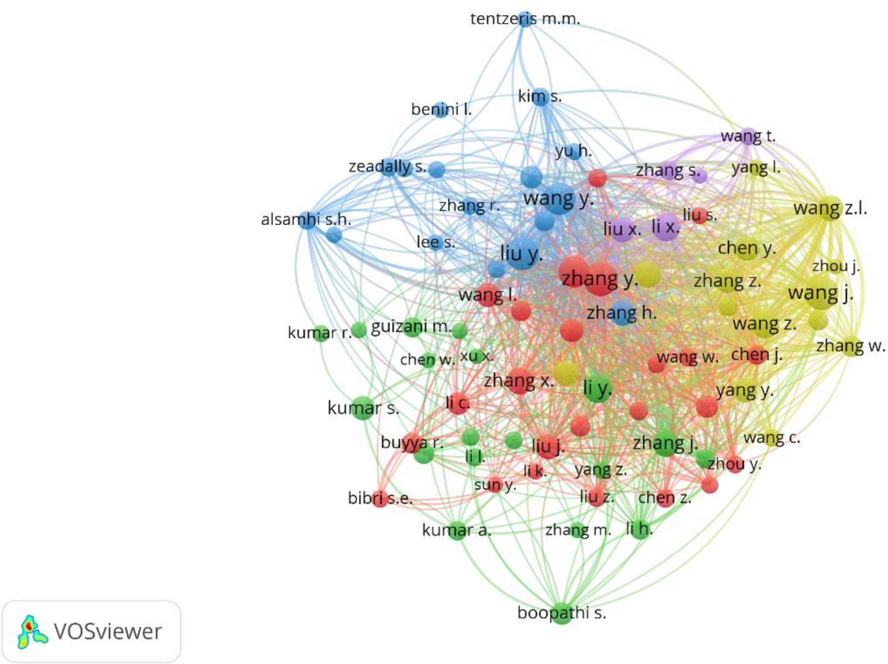

Figure 7. Density Visualization

Source: Data Analysis Result, 2024

This VOSviewer visualization portrays a network map of author collaborations. The map is color-coded to distinguish between different clusters of authors, indicating varied groups or communities that frequently collaborate on research projects. The nodes represent individual researchers, with node size likely denoting the number of publications or the centrality of the author within the network. The links between the nodes signify co-authorships, where a thicker line might indicate more frequent collaboration between the authors. Prominent among the nodes are several with the surnames "Wang," "Zhang," and "Liu," which are common in Chinese academic circles, suggesting a strong contribution from Chinese researchers to this field. This map is a visual representation of the collaborative nature and the interconnectivity of modern scientific research, highlighting how knowledge creation in advanced technology fields often involves extensive collaboration across researchers and institutions.

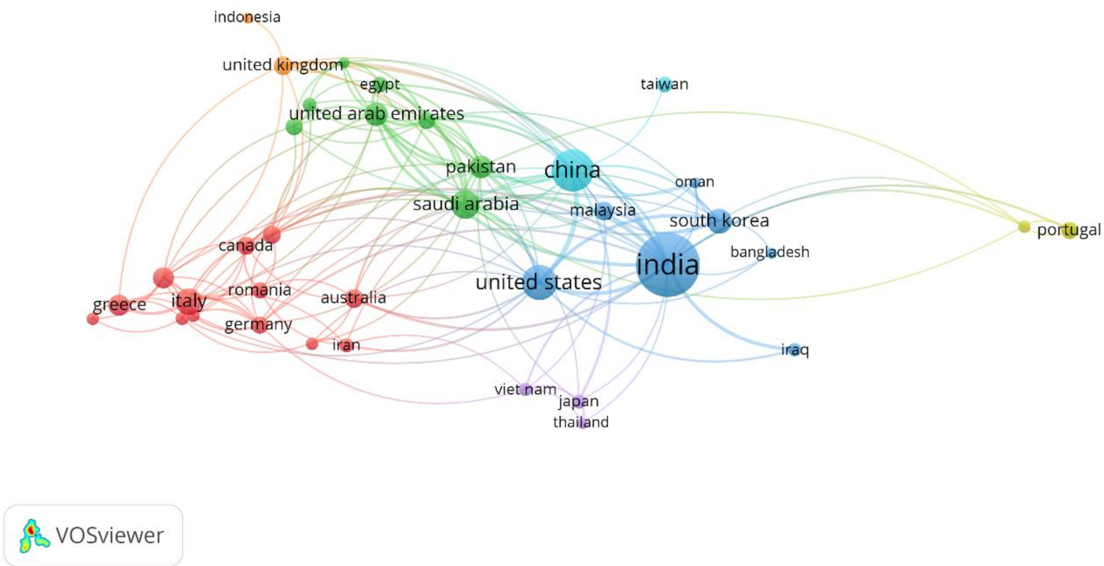

Figure 7. Country Visualization

Source: Data Analysis Result, 2024

The VOSviewer network map displayed illustrates the international collaboration between various countries. The nodes represent different countries, with their size potentially indicating the volume of research output or the intensity of research activity within that nation. The links between the nodes symbolize collaborations, where the thickness of the lines could suggest the frequency or strength of partnerships between the countries. Notably, India and the United States emerge as central nodes with dense connections, indicating they are key players in this research field with numerous international collaborations. Smaller nodes like Portugal and Oman, though less central, still show connectivity, highlighting their involvement in the global research network.

Discussion

1. Evolution of Research Focus

Initially, IoT research was heavily concentrated on foundational technologies and infrastructure development, as seen in the significant volume of literature addressing network security, sensor networks, and data management capabilities. Over time, however, there has been a noticeable shift towards applications that address sustainable development and energy efficiency. This transition reflects a broader societal shift towards sustainability and the increasing demand for technologies that can contribute positively to environmental goals. The integration of IoT with renewable energy sources and smart grids underscores this trend, highlighting a growing emphasis on not just managing but actively reducing energy consumption.

2. Interdisciplinary Research and Collaboration

The diversity of research themes captured in the keyword visualization maps reveals the inherently interdisciplinary nature of IoT research. It spans computer science, engineering, environmental science, and social sciences, indicating that successful IoT applications are built on a convergence of insights from various fields. This interdisciplinary approach is crucial for tackling complex problems like sustainable development, where technical solutions must align with environmental objectives and social needs. The analysis of collaborations between authors and institutions, especially those involving leading contributors from various countries, showcases the global effort in advancing IoT technologies. Countries like the United States, China, and India are pivotal in this research network, not only contributing a significant volume of scholarly work but also establishing numerous collaborative links with other nations. This global network of knowledge exchange enhances the development and dissemination of IoT innovations, ensuring that advancements are shared and adapted across different geographical and economic contexts.

3. Challenges in IoT Implementation

Despite the promising advancements in IoT for energy efficiency, several challenges persist that hinder broader adoption. First, the integration of IoT systems often requires substantial upfront investment in infrastructure and technology, which can be a significant barrier for smaller enterprises or less developed regions. Additionally, concerns regarding the security and privacy of IoT systems continue to be a significant issue, as the interconnected nature of these devices presents multiple vulnerabilities that could be exploited by malicious entities. Another challenge is the environmental impact of the IoT devices themselves. While they are deployed for enhancing energy efficiency and monitoring environmental conditions, the production, use, and disposal of these devices generate electronic waste and other environmental burdens. Addressing these lifecycle impacts is essential for ensuring that IoT solutions contribute net positive benefits to sustainability goals.

4. Policy Implications

The findings of this study have significant implications for policymakers. There is a clear need for policies that support the development and integration of IoT solutions in a way that aligns with environmental and economic goals. Incentives for adopting green technologies, subsidies for research and development, and standards for data security and device interoperability could all play roles in accelerating IoT adoption and maximizing its benefits. Moreover, international cooperation in policy formulation could facilitate the efficient rollout of IoT solutions across borders, ensuring that advancements in one region can be leveraged in others. Such cooperation is particularly crucial in addressing global challenges like climate change, where the collective action enabled by shared technologies can lead to more effective solutions.

5. Future Research Directions

Looking forward, it is evident that continued research is needed not only on the technological aspects of IoT but also on its social, economic, and environmental impacts. Future studies could explore the long-term effects of widespread IoT implementation on energy consumption patterns and environmental quality. Additionally, research into more sustainable materials and manufacturing processes for IoT devices could help mitigate the negative impacts associated with their lifecycle. The field would also benefit from further studies on the integration of artificial intelligence and machine learning with IoT systems, enhancing their capabilities for predictive analytics and automated decision-making. Such advancements could lead to even greater efficiencies and more innovative solutions to complex environmental challenges.

CONCLUSION

This bibliometric analysis has illuminated the significant growth and evolving dynamics within the field of IoT, particularly in its application to energy efficiency, environmental impact, and resource management. The study highlighted a shift from foundational technological research towards applications that promote sustainable development and smarter energy management, reflecting broader global sustainability objectives. Despite facing challenges such as high initial costs, security concerns, and environmental impacts of the devices themselves, the potential of IoT solutions in enhancing global energy efficiency remains vast. The findings underscore the importance of continued interdisciplinary collaboration and robust policy support to overcome these barriers. Future research should focus on advancing IoT's technological integration with renewable energy systems, improving the sustainability of IoT devices, and further exploring the socio-economic impacts of IoT implementations. This study lays a foundation for understanding how IoT can be strategically deployed to meet the urgent demands of energy sustainability and environmental stewardship, urging a concerted effort to harness this technology for a more sustainable future.

REFERENCES

[1] C. Falkenreck, G. Leszczyński, and M. Zieliński, "What drives the successful launch of IoT-related business models?," *J. Bus. Ind. Mark.*, vol. 38, no. 13, pp. 180–194, 2023.

[2] R. Y. Zhong, L. Wang, and X. Xu, "An IoT-enabled real-time machine status monitoring approach for cloud manufacturing," *Procedia Cirp*, vol. 63, pp. 709–714, 2017.

[3] A. Sadeghi-Niaraki, "Internet of Thing (IoT) review of review: Bibliometric overview since its foundation," *Futur. Gener. Comput. Syst.*, vol. 143, pp. 361–377, 2023.

[4] M. A. Khan and K. Salah, "IoT security: Review, blockchain solutions, and open challenges," *Futur. Gener. Comput. Syst.*, vol. 82, pp. 395–411, 2018.

[5] Y. Liu, C. Yang, L. Jiang, S. Xie, and Y. Zhang, "Intelligent edge computing for IoT-based energy management in smart cities," *IEEE Netw.*, vol. 33, no. 2, pp. 111–117, 2019.

[6] S. Malathy, K. Sangeetha, C. N. Vanitha, and R. K. Dhanaraj, "Integrated architecture for IoTSG: internet of things (IoT) and smart grid (SG)," *Smart Grids Internet Things An Energy Perspect.*, pp. 127–155, 2023.

[7] M. Farjana, A. B. Fahad, S. E. Alam, and M. M. Islam, "An iot-and cloud-based e-waste management system for resource reclamation with a data-driven decision-making process," *IoT*, vol. 4, no. 3, pp. 202–220, 2023.

[8] N. Aloui, W. Almukadi, and A. Belghith, "Towards an IOT Approach for Smart Waste Management based on Context Ontology: A Case Study," *Eng. Technol. Appl. Sci. Res.*, vol. 13, no. 1, pp. 10186–10191, 2023.

[9] N. N. Pujianik, I. N. S. Parwata, I. M. O. G. Antara, K. Kazumi, and A. Rivai, "Development of an IoT-Based Real-Time Monitoring System and LFA to Improve the Efficiency and Performance of the Wastewater Treatment Plant at Udayana University Hospital," in *Journal of the Civil Engineering Forum*, 2023, pp. 109–116.

[10] Y. Wungcharoen, "IoT adoption in SME manufacturers in Thailand," 2022.

[11] S. E. Bibri, "The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability," *Sustain. cities Soc.*, vol. 38, pp. 230–253, 2018.

[12] B. Esmaeilian, J. Sarkis, K. Lewis, and S. Behdad, "Blockchain for the future of sustainable supply chain management in Industry 4.0," *Resour. Conserv. Recycl.*, vol. 163, p. 105064, 2020.

[13] S. H. Alsamhi, O. Ma, M. S. Ansari, and F. A. Almalki, "Survey on collaborative smart drones and internet of things for improving smartness of smart cities," *Ieee Access*, vol. 7, pp. 128125–128152, 2019.

[14] M. Slabicki, G. Premsankar, and M. Di Francesco, "Adaptive configuration of LoRa networks for dense IoT deployments," in *NOMS 2018-2018 IEEE/IFIP Network Operations and Management Symposium*, IEEE, 2018, pp. 1–9.

[15] L. Yu, S. Qin, M. Zhang, C. Shen, T. Jiang, and X. Guan, "A review of deep reinforcement learning for smart building energy management," *IEEE Internet Things J.*, vol. 8, no. 15, pp. 12046–12063, 2021.

[16] S. Zeadally, F. K. Shaikh, A. Talpur, and Q. Z. Sheng, "Design architectures for energy harvesting in the Internet of Things," *Renew. Sustain. Energy Rev.*, vol. 128, p. 109901, 2020.

[17] J.-W. Han, M. Zuo, W.-Y. Zhu, J.-H. Zuo, E.-L. Lü, and X.-T. Yang, "A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends," *Trends Food Sci. Technol.*, vol. 109, pp. 536–551, 2021.

[18] H. Sharma, A. Haque, and Z. A. Jaffery, "Maximization of wireless sensor network lifetime using solar energy harvesting for smart agriculture monitoring," *Ad Hoc Networks*, vol. 94, p. 101966, 2019.

[19] T. M. Behera, S. K. Mohapatra, U. C. Samal, M. S. Khan, M. Daneshmand, and A. H. Gandomi, "I-SEP: An improved routing protocol for heterogeneous WSN for IoT-based environmental monitoring," *IEEE Internet Things J.*, vol. 7, no. 1, pp. 710–717, 2019.

[20] H. Elahi, K. Munir, M. Eugeni, S. Atek, and P. Gaudenzi, “Energy harvesting towards self-powered IoT devices,” *Energies*, vol. 13, no. 21, p. 5528, 2020.