ISSN | JAEST

Journal of Applied Engineering and Sustainable Technologies
Vol. 1, No. 1, 2026, pp. 35–45

A BIBLIOMETRIC EXAMINATION OF DIGITAL TWIN APPLICATIONS IN SUSTAINABLE ENERGY

[1]Loso Judijanto, [2]Tina Isnaeni
[1]IPOSS Jakarta, [2]Universitas Nusa Putra

ARTICLE INFO

Article history
Received: [September, 2026]
Revised: [September, 2026]
Accepted: [September, 2026]
Available Online: [September, 30 2026]

Keywords
Digital Twin; Sustainable Energy; Energy Systems; Renewable Energy; Energy Management; Artificial Intelligence

DOI

***Corresponding* Author:**

Name: Loso Judijanto
Institution Address: IPOSS Jakarta
e-mail: losojudijantobumn@gmail.com

ABSTRACT

The rapid development of digital technologies has created new opportunities to improve the efficiency, flexibility, and sustainability of energy systems, with Digital Twin technology emerging as an important approach for integrating real-time monitoring, simulation, prediction, and optimization. This study aims to examine the development, intellectual structure, thematic evolution, and collaboration patterns of research on Digital Twin applications in sustainable energy. A bibliometric analysis was conducted using scientific publications related to Digital Twin and sustainable energy, with the literature examined through citation analysis, keyword co-occurrence analysis, temporal overlay analysis, density visualization, and collaboration mapping at the author, institutional, and country levels. The findings indicate that digital twin, energy systems, energy management, energy efficiency, and optimization constitute central themes in the research landscape. The temporal analysis further reveals increasing attention to machine learning, deep learning, predictive analytics, forecasting, predictive maintenance, renewable energy, energy storage, and predictive control systems. Highly cited studies demonstrate a parallel development from foundational Digital Twin architectures and integrated energy-system scheduling toward applications involving smart grids, renewable energy, electric vehicles, and AI-supported optimization. The collaboration analysis shows a globally distributed research landscape involving multiple countries and research communities, although institutional and author collaboration remains relatively fragmented. The findings indicate that Digital Twin research in sustainable energy is shifting from foundational system representation toward AI-enabled, predictive, and integrated applications that support more efficient and sustainable energy-system operation.

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A. INTRODUCTION

The global energy system is undergoing a significant transformation process aimed at enhancing energy efficiency, reducing greenhouse-gas emissions, renewable energy integration, and increasing the resilience of energy infrastructures. The move toward sustainability in energy use is characterized by increased complexity of the energy systems owing to variability of renewable power production, the dynamic nature of energy consumption, and decentralization and interconnection of electricity networks. The above aspects of the energy system make necessary the management of the energy system based on more flexible approaches than monitoring and control of traditional type. As a result,

digitalization has recently become an integral part of the energy transition, including IoT, AI, ML, cloud computing, advanced analytics, and cyber-physical systems. Recently, some researchers have suggested that digitalization through these technologies could help modernize the energy grid, facilitate renewable energy integration, demand response, and energy efficiency programs through continuous monitoring (Abdessadak et al., 2025).

In this context, Digital Twin (DT) technology has been recognized as a significant technological paradigm within the digital transformation. DT can be defined as a dynamic virtual replica of a physical entity that interacts with its physical version through data and communication technologies. In contrast to a conventional simulation model, a DT involves creating a long-term connection with the physical system that helps in feeding information from the physical space to the virtual one, and in more sophisticated cases, provides feedback from the virtual environment to make decisions. The significance of integrating the physical and virtual worlds with the help of IoT and data analytics is highlighted by (Alao et al., 2024). This integration makes it possible to use DT in such applications as monitoring, forecasting, fault detection, and decision-making. In a similar way, (Al-Shetwi et al., 2025) distinguish DTs from traditional cyber-physical approaches highlighting the capability of creating a deeper connection between physical objects and their virtual counterparts.

Energy is one of the areas where digital twins might be used since energy resources and infrastructures include highly complicated and constantly changing processes. The technology may be used in various stages of the energy chain, such as energy generation, transmission, distribution, storage, consumption, and management. For instance, in renewables, digital twins may be used for monitoring, maintenance, diagnosing, performance, and forecasting purposes. The work of do (do Amaral et al., 2023) presents a complete literature review which proves that there has been an expansion of Energy Digital Twins use from energy generation to energy distribution, storage, and consumption and reveals both benefits and challenges related to the technology. From the results obtained, it can be concluded that the research area has moved forward from theoretical considerations to application-based studies.

DT technology becomes relevant in particular to renewable energy generation. Continuous monitoring is necessary for photovoltaic systems, wind energy generation farms, hydropower plants, energy storage methods, and hybrid renewable energy systems due to possible influence of environmental factors, degradation of equipment, operation unpredictability, and variability of energy demand. For example, (Das et al., 2024) argue that monitoring, maintenance, optimization, fault detection, and diagnostics represent crucial applications of DT technology in photovoltaic systems. Also, (Fuller et al., 2020) show the growing significance of DT technologies in wind energy systems for forecasting, condition monitoring, and predictive maintenance. The above applications show that DT technology can help in creating sustainable future not only through digitalization of energy infrastructure, but also through improvement of its design, maintenance, and optimization.

The application of DTs in conjunction with AI and ML increases even further the opportunity for their impact on the development of sustainable energy. AI-based DTs will be able to work with huge amounts of real-time data, detect patterns, forecast failures of equipment, optimize energy generation, and help develop more agile management systems. As noted by (Ghenai et al., 2022), the combination of DTs and AI has become an important issue in the study of energy transitions, renewable energy, microgrids, and energy efficiency. However, there are still some difficulties associated with the implementation of the technology, such as high costs, cybersecurity, integration, and complexity.

While the number of studies dedicated to Digital Twins in energy applications has grown significantly, it is still characterized by fragmentation in relation to technology, energy sector, objective of applications, and community carrying out research. The previous review studies tended to pay attention to a specific area of the field. Some studies tend to explore applications of Energy Digital Twins in general, while others pay attention to photovoltaic applications, wind energy, power generation and distribution, smart grids, energy management, or use of DTs and AI. According to (Ismail et al., 2024), DT applications relate to different areas of electricity and energy, while more recent reviews create taxonomies of renewable-energy applications. Such fragmentation results in a necessity for a systematic study of the evolution of intellectual/conceptual framework of the field. The conventional approach to literature review allows one to integrate information collected from the selected papers, but it does not necessarily lead to identification of

publication growth trends, important publications/authors, institutional/geographical contributions, collaboration patterns, citation structures, or evolving themes within the field. Bibliometrics offers an alternative approach, which allows mapping and visualization of large corpora of scientific literature quantitatively. Using citation analysis, co-authorship analysis, co-citation analysis, bibliographic coupling, and keyword co-occurrence analysis, one can reveal the intellectual structure and evolution of themes in the emerging field of research.

Notably, bibliometric researches in recent times reveal that the field of DT-energy is growing quickly. For instance, (Kandemir et al., 2024) conducted a Scopus bibliometric study about DTs, AI, and IoT in energy management and discovered increasing research interest with buildings and manufacturing being identified as key contexts. Besides, their results suggest an increase in the use of supervised learning and deep-learning approaches in energy management DT researches. On the other hand, recent bibliometric researches have also looked into specific aspects like sustainable urban energy systems and building energy efficiency using DTs. This shows the importance of bibliometric research approaches as well as the distribution of research on the link between Digital Twins and sustainable energy in various research streams. As a result, what is at the heart of this study is not the mere fact that no study has been conducted on Digital Twins in energy. The problem lies in the fact that there has not been any integrative bibliometric assessment of the development, knowledge structure, topic evolution, key contributors, and new areas of research in relation to the application of Digital Twin technology in sustainable energy. Such an analysis will be needed in order to understand the development of this field of research, the topics explored, and the gaps remaining. This study conducts a bibliometric examination of Digital Twin applications in sustainable energy. The study aims to systematically map the development of the research field and identify its major intellectual, conceptual, and collaborative structures.

B. METHODS

A bibliometric approach was used for the systematic evaluation of the evolution and research trends of Digital Twin technology in sustainable energy. Bibliographic information was obtained from the Scopus database due to the high relevance of the peer-reviewed scientific literature available in this database and standardization of the bibliographic metadata of publications. The keywords used for building the search query were associated with the key phrases Digital Twin, sustainable energy, renewable energy, energy system, energy management, and smart energy. Publications were searched for within the fields of title, abstract, and keywords, which allowed identifying those publications specifically dedicated to the research problem. Then, the obtained data was analyzed to eliminate the duplicates, irrelevant and incomplete records.

A bibliometric dataset acquired through Scopus was exported in a bibliometrically-analyzable format with details on the author, year of publication, title, abstract, keywords, affiliation, country, number of citations and references. The analysis centered on a range of indices in order to assess the structure and evolution of the field with the aid of publication patterns, citation patterns, influential authors, sources, countries, institutions, keyword use and themes of research. Particular focus was laid on keyword co-occurrence and publication interrelationships since these indices could shed light on the structural aspects and thematic focus of Digital Twin research on sustainable energy. Citation data was also analyzed in order to pinpoint key publications that have made major contributions to the evolution of the field.

Visualizing and mapping of the bibliographic data were carried out using VOSviewer software. With the help of the software, bibliometric networks were constructed and visualized on the basis of co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation analysis depending on the nature of the database acquired. In the case of the co-occurrence analysis of keywords, frequently used keywords in the selected publications were visualized to see the clusters that represent the main themes of the research and their interconnections. Co-authorship analysis was done to analyze the pattern of collaborations among the researchers and countries, and the citation and bibliographic coupling analysis was performed to see the influential publications and intellectual links in the field.

C. RESULTS AND DISCUSSION

1. Keyword Co-Occurrence Network

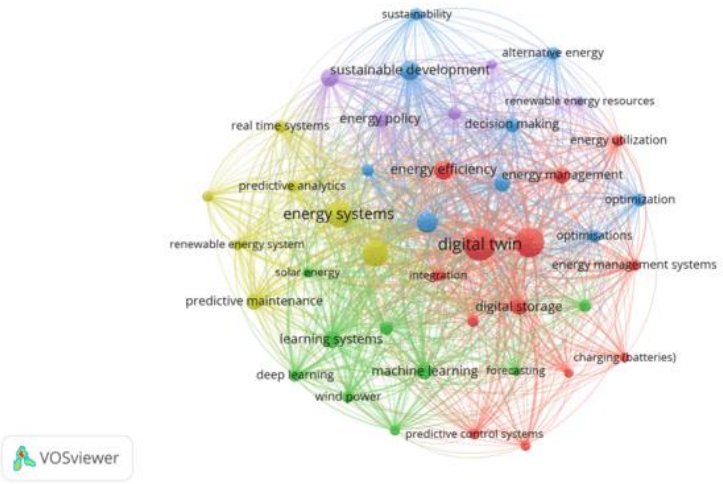


Figure 1. Network Visualization
Source: Data Analysis Result, 2026

Figure 1 represents the intellectual structure of Digital Twin applications in sustainable energy. It is very well connected, thus signifying that Digital Twin research in the context of energy is not about one particular technology only; it involves energy management, renewable energy, artificial intelligence, optimization, sustainability, and decision-making. “Digital twin” stands out as the most popular keyword, which is shown by its relatively large node and numerous links to other keywords. The fact that it is located near the center of the network signifies that Digital Twin acts as the main conceptual point around which various research themes cluster. The group of the color red is indicative of a robust research thread about energy management, optimization, energy efficiency, and energy usage. Terms such as energy management, energy management system, energy efficiency, optimization, optimisation, digital storage, charging (battery), and predictive control systems have a close relationship with the digital twin. In this arrangement, there is an indication that the Digital Twin technology is under increased exploration as the means through which energy systems can be monitored, controlled, simulated, and optimized.

These clusters of green and yellow color reflect the application of Digital Twin technology along with artificial intelligence, prediction, renewable energy, and intelligent energy systems. The green cluster comprises important concepts including machine learning, deep learning, learning systems, wind power, prediction, and predictive maintenance, implying that the use of Digital Twin technology is becoming more integrated with data-based technologies in order to facilitate predictions, diagnostics, and maintenance. On the other hand, the yellow cluster consists of the concepts of energy systems, prediction, renewable energy system, solar energy, real-time systems, and predictive maintenance. Overall, the two clusters show the shift from simple virtual models towards intelligent models in renewable energy environments. The bluish and purplish clusters emphasize the larger sustainability and strategy aspects of the area of research. The use of keywords such as sustainability, sustainable development, alternative energy, renewable energy resources, energy policy, decision making, and energy efficiency shows the relationship of Digital Twin research to broader environmental and institutional issues. The stronger relationships between these keywords and the core Digital Twin keyword show that in the literature, Digital Twin technology is being used more and more not only as an engineering technique but also as a tool for sustainable energy transition, resource efficiency, and decision making based on evidence.

The network shows an interdisciplinary and evolving research area that is characterized by three interrelated dimensions regarding the use of Digital Twin in sustainable energy: smart energy system operation, integration of renewable energy sources, and sustainability-driven decision making. The highly connected nodes of Digital Twin, energy systems, energy management, machine learning, predictive analytics, renewable energy, and sustainability show that all those topics are important thematic elements of the research domain. On the other hand, the emergence of terms

like digital storage, battery charging, predictive control systems, and energy policies is a sign of the development of new directions related to energy storage, autonomous control, and energy transition facilitated by energy policies.

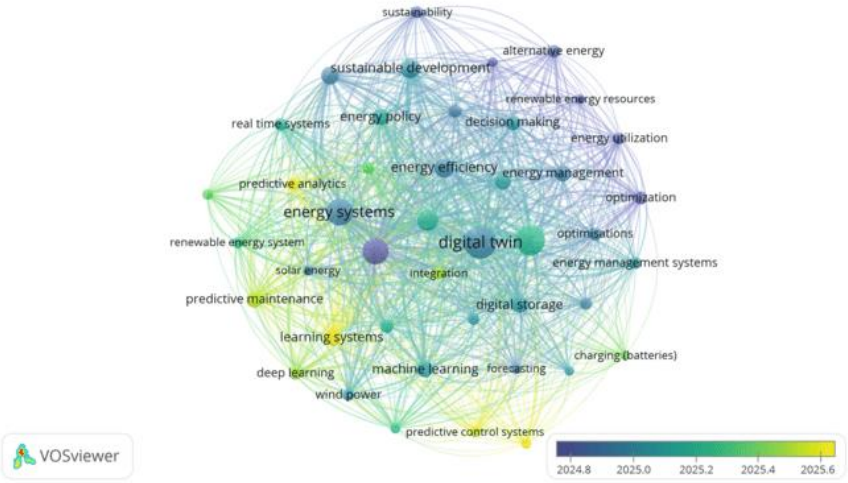


Figure 2. Overlay Visualization
Source: Data Analysis Result, 2026

Figure 2 displays the evolution through time of keywords used in research related to the application of Digital Twin technology in sustainable energy, where the colors represent values between 2024.8 (purple/blue) and 2025.6 (yellow). The main keyword "digital twin" is shown in a dominant position and is connected to many other concepts, which proves its continued importance over the whole examined period. Previous research seems to be related to fundamental and system concepts, such as sustainable development, energy systems, energy policies, decision making, and energy management. This shows that earlier research was concerned with defining the place of Digital Twin technology in the energy system management context.

The more recent studies have green to yellow keywords, including predictive analytics, predictive maintenance, machine learning, deep learning, forecasting, wind power, solar energy, predictive control systems, and charging (batteries). The more yellow shade of these keywords shows their more recent use or relevance to the topic. This means that there has been a transition from the usage of the Digital Twin concept to the use of smarter and predictive energy applications. In particular, the closeness and interrelation of machine learning, forecasting, predictive maintenance, renewable energy, and predictive control show integration of Digital Twin and artificial intelligence technologies for the monitoring, forecasting, and controlling energy systems.

The temporal map shows progression from the application of concepts and system level concepts to a more advanced form of research. Themes of sustainability, energy systems, and energy management seem to be the foundation of these concepts while newer themes such as renewable energy integration, predictive analytics, AI, energy storage, and intelligent control dominate. It seems from the emergence of digital storage, battery charging, wind energy, solar energy, and predictive control systems that research in the newer part of the spectrum is now focusing more on the practical implementation of Digital Twins in energy systems. This temporal development indicates that the field is progressing towards AI-driven Digital Twins which can optimize energy systems.

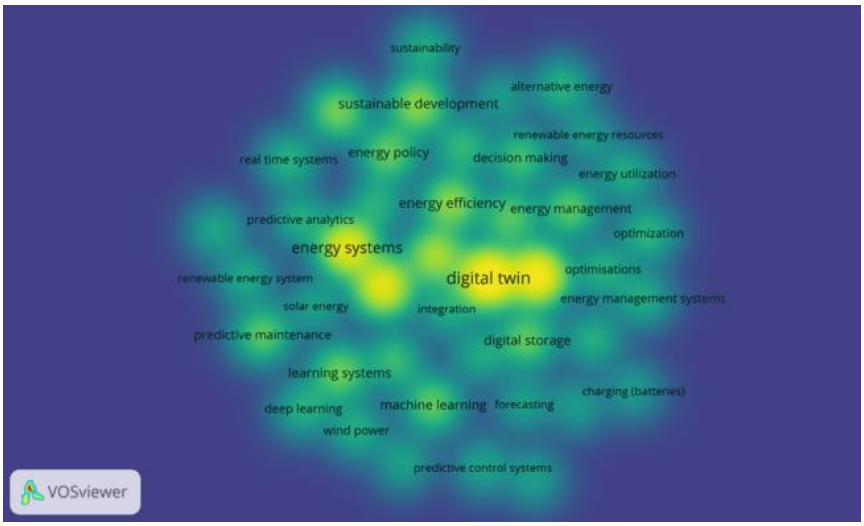


Figure 3. Density Visualization
Source: Data Analysis Result, 2026

Figure 3 indicates that research on Digital Twin applications in sustainable energy is concentrated around several highly prominent themes. The brightest areas are centered on "digital twin," "energy systems," and their surrounding concepts, indicating that these terms occur frequently and have strong relationships with other keywords. Closely associated topics include energy management, energy efficiency, optimization, energy management systems, and integration, showing that Digital Twin research is strongly oriented toward improving the monitoring, management, and optimization of energy systems. A second concentration can be observed around sustainable development, sustainability, energy policy, and renewable energy resources, demonstrating that Digital Twin applications are also closely connected to broader sustainability objectives. These regions are characterized by more focused approaches to research, such as machine learning, deep learning, predictive maintenance, forecasting, wind power, solar energy, digital storage, charging (of batteries), and predictive control. Even though they may seem less clustered than the core topic of Digital Twin-energy systems, their closeness in space means that they form part of the larger research field. It seems like the field is moving away from the traditional management of energy systems to predictive techniques and energy storage.

2. Co-Authorship Analysis

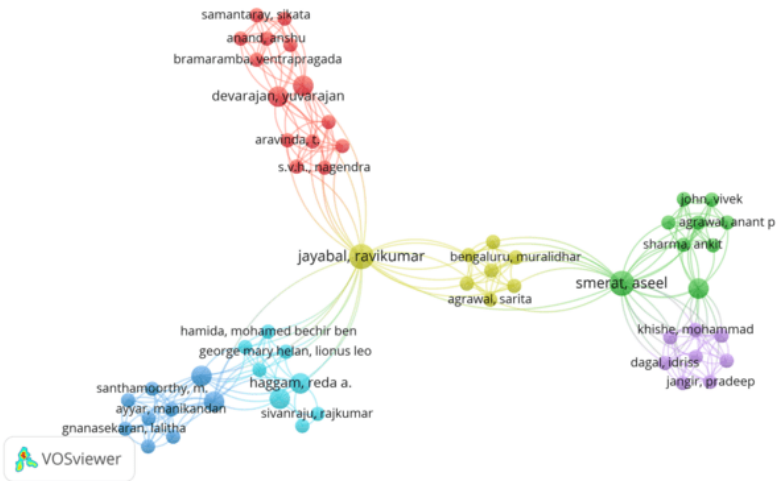


Figure 4. Author Visualization
Source: Data Analysis Result, 2026

A collaboration structure, which is fragmental and interconnected at the same time, is demonstrated in Figure 4 in relation to research on Digital Twin applications in sustainable energy. There are some distinctive author clusters, where each of them is a relatively compact research collaboration community. For instance, one of the author clusters is represented by red color in the upper left corner and comprises S. V. H. Nagendra, Aravinda T., Devarajan, Yuvarajan, and Anand, Anshu, whereas another author cluster of blue color in the lower left corner comprises Mohamed Bechir

Ben Hamida, George Mary Helan, Ionius Leo, and Haggam, Reda A. In turn, the yellow author cluster, which is centered around Jayabal, Ravikumar, acts as a bridge among other author clusters. Thus, the green author cluster in the right side with its center in Smerat, Aseel is connected with John, Vivek, Agrawal, Anant P., and Sharma, Ankit, whereas the purple author cluster comprises Khishe, Mohammad, Dagal, Idriss, and Jangir, Pradeep. Links between the author clusters, especially with regard to the yellow author cluster, suggest some cross-cluster collaboration; however, in general, the network is marked by several relatively separate research communities.

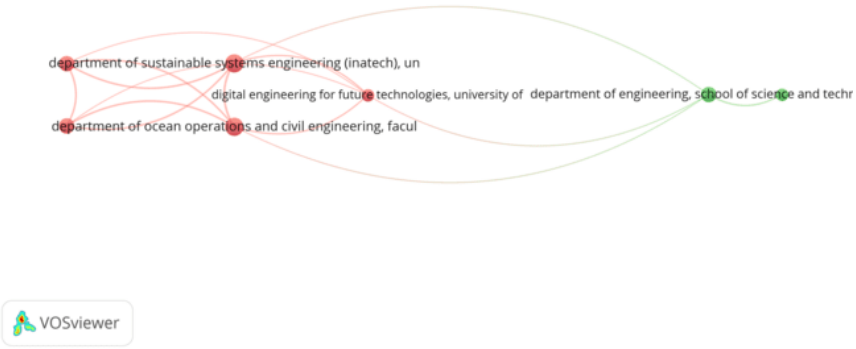


Figure 5. Institution Visualization
Source: Data Analysis Result, 2026

Figure 5 indicates a relatively limited and concentrated pattern of institutional collaboration within research on Digital Twin applications in sustainable energy. The red cluster is dominated by several engineering-oriented units, including the Department of Sustainable Systems Engineering (Inatech, University of Freiburg), Department of Ocean Operations and Civil Engineering, and Digital Engineering for Future Technologies, which are closely interconnected through multiple collaboration links. On the right, the green cluster represents another institutional group consisting of an engineering/school of science and technology unit and a related institution. The links connecting the red and green clusters indicate cross-institutional collaboration, although the relatively small number of visible institutions and the clear separation between the two clusters suggest that the research network remains highly specialized and not yet broadly distributed across institutions.

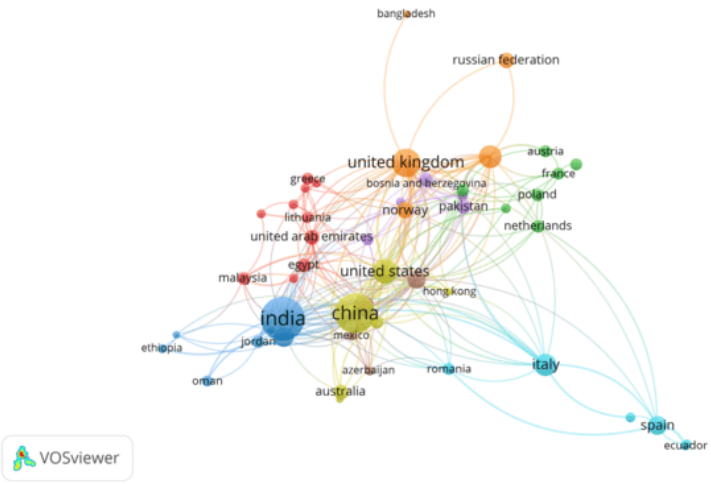


Figure 6. Country Visualization
Source: Data Analysis Result, 2026

Figure 6 shows a vast and extremely interconnected international research map regarding the application of Digital Twins in sustainable energy. India and China represent the most prominent nodes, which implies a significant number of publications and collaboration internationally, whereas the United Kingdom and the United States are located at the

center of the research network, having many links with different countries. Such countries as Italy, Norway, the Netherlands, Poland, France, Austria, and Greece belong to the collaborative group of European countries, whereas Pakistan, Malaysia, Egypt, United Arab Emirates, Jordan, Australia, Mexico, Romania, Bangladesh, Russia, Spain, and Ecuador also provide additional links in the network. The large number of connecting lines between different countries shows a high level of international cooperation and proves that Digital Twin research in sustainable energy became a truly global and interdisciplinary field of study, with interconnection among Asian, European, and North American scientific communities. However, the existence of smaller nodes connected to bigger central countries shows differences in the number of publications and collaboration among them.

3. Citation Analysis

Table 1. Top Cited Research

Citations	Author and year	Title
176	(Abdessadak et al., 2025)	Impacts of digitalization on smart grids, renewable energy, and demand response: An updated review of current applications
170	(Mahmood et al., 2024)	Digital twins based day-ahead integrated energy system scheduling under load and renewable energy uncertainties
159	(Rajaperumal & Columbus, 2025)	Recent trends of digital twin technologies in the energy sector: A comprehensive review
156	(Singh et al., 2022)	Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability
150	(Steindl et al., 2020)	Generic digital twin architecture for industrial energy systems
147	(Tao et al., 2018)	Advancements in digital twin technology and machine learning for energy systems: A comprehensive review of applications in smart grids, renewable energy, and electric vehicle optimisation
130	(Tao et al., 2019)	Advances in emerging digital technologies for energy efficiency and energy integration in smart cities
116	(Valizadeh et al., 2026)	Digital Twin Technology for Renewable Energy, Smart Grids, Energy Storage and Vehicle-to-Grid Integration: Advancements, Applications, Key Players, Challenges and Future Perspectives in Modernising Sustainable Grids
113	(Yousef et al., 2023)	Transforming the electrical grid: the role of AI in advancing smart, sustainable, and secure energy systems
111	(You et al., 2022)	Artificial Intelligence for Management of Variable Renewable Energy Systems: A Review of Current Status and Future Directions

Source: Scopus, 2026

Table 1 shows that the most cited research on Digital Twin applications in sustainable energy is dominated by studies addressing digitalization, smart grids, renewable energy, energy-system optimization, and sustainability. (Abdessadak et al., 2025) received the highest number of citations (176) through their review of digitalization impacts on smart grids, renewable energy, and demand response, followed closely by (Mahmood et al., 2024) with 170 citations, which focuses specifically on Digital Twin-based day-ahead scheduling under load and renewable-energy uncertainties. Other highly cited studies, including (Rajaperumal & Columbus, 2025), (Singh et al., 2022), emphasize the development of Digital Twin technologies and broader Energy System 4.0 concepts, while (Steindl et al., 2020) provides a foundational contribution through a generic Digital Twin architecture for industrial energy systems. More recent publications by (Tao et al., 2018), (Tao et al., 2019), (Valizadeh et al., 2026) demonstrate an increasing integration of Digital Twins with machine learning, energy efficiency, renewable energy, energy storage, electric vehicles, and smart-grid optimization. The inclusion of (Yousef et al., 2023), (You et al., 2022) further highlights the growing role of artificial intelligence in developing smart, sustainable, and adaptive energy systems.

4. Discussion

The bibliometric results illustrate that studies related to Digital Twin application in sustainable energy have evolved into an interdisciplinary field of research which bridges digital technology to energy system optimization,

renewable energy, sustainability, and intelligent decision making. According to the keyword co-occurrence analysis, "digital twin" forms the core of intellectual structure in terms of connections with energy systems, energy management, energy efficiency, optimization, sustainable development, and renewable energy sources. This shows that Digital Twin research has gradually become an enabler technology in terms of representation, monitoring, and optimization of complex energy systems. In other words, Digital Twins are not examined as a standalone digital technology but rather within the context of energy system efficiency and coordination.

Moreover, it can be seen that the theme structure also shows that energy management and optimization form one of the key application areas of Digital Twin technology. The strong correlations between the terms digital twin, energy management, energy management system, energy efficiency, and optimization reveal the interest of researchers in employing virtual models of real-world energy assets to facilitate decision-making processes. Such results corroborate the findings of (Mahmood et al., 2024) who studied Digital Twin-enabled day-ahead scheduling for integrated energy systems under load and renewable-energy uncertainties. It proves the significance of Digital Twins in dealing with the dynamic nature of the modern energy systems. Likewise, (Steindl et al., 2020) proposed a generic Digital Twin framework for industrial energy systems, which is a significant technological basis for future applications. Thus, the popularity of such themes is an indicator of moving on from creating Digital Twin frameworks to their implementation in energy management and optimization.

The next finding refers to the combination of Digital Twins with artificial intelligence and predictive analytics. Machine learning, deep learning, predictive analytics, forecasting, and predictive maintenance are among the related keywords in the cluster. The link between these two clusters means that the importance of Digital Twins increasingly relies on their ability to combine the data gathered from the physical objects in real time and perform analysis and predictions on the basis of this data. Here, the concept of Digital Twin is a digital representation of an energy asset combined with the ability to perform the forecasts about its behavior and find out any possible faults. The relevance of these clusters is confirmed by the work by (Tao et al., 2018) who present a review dedicated to the interaction of Digital Twin technology and machine learning in smart grids, renewable energy, and electric vehicle optimization. The bibliometric analysis shows a trend toward AI-enhanced Digital Twins, where machine learning and predictive analytics help Digital Twins adapt to changes in energy conditions.

The results have also indicated that there is an ever-growing focus on renewables and energy storage systems. Such terms as solar energy, wind energy, renewable energy system, digital storage, and charging (batteries) indicate that Digital Twin research is moving away from traditional energy infrastructures towards technologies that play a crucial role in the energy transition process. The significance of this trend can be explained by such features of renewable-energy systems as variability and sensitivity to the changes in environmental conditions. The use of Digital Twins can create a virtual representation of such systems that will help with forecasting, control, maintenance, and optimization of renewable energy systems. The high-level citations of the papers by (Rajaperumal & Columbus, 2025), (Valizadeh et al., 2026) confirm that there is a growing interest in Digital Twin technology and its use in energy systems, including renewable energy systems, smart grids, energy storage, and vehicle-to-grid integration.

It also confirms the trend towards changes in the focus of the research. Earlier themes are more closely connected with sustainable development, sustainability, energy policy, energy systems, and decision-making. More recent topics are mainly related to machine learning, predictive analytics, forecasting, predictive maintenance, wind power, solar energy, and predictive control systems. This trend shows that the research topic has moved from the abstract discussions of digitalization and sustainable energy to more technical issues. It is also confirmed by the literature review. Earlier papers like (Steindl et al., 2020) have investigated Digital Twin architecture. Recent researches increasingly explore integrated applications using machine learning, smart grids, renewable energy, electric vehicles, and energy storage. Hence, the literature seems to move from "what Digital Twins are" to "how Digital Twins can operate and optimize sustainable energy systems."

In the density visualizations, we can observe that the highest density is at Digital Twin, energy system, and energy management-related nodes, while the nodes of AI, predictive maintenance, renewable energy, storage, and predictive

control are slightly more specialized. It appears that energy-system management will continue to be the core body of knowledge for this field, while the application of artificial intelligence for prediction and renewable energies are among its extensions. The presence of these two topics together means that in the future, the Digital Twin architecture is likely to be more integrated rather than focusing on one function related to energy.

The collaboration analysis gives yet another angle to consider the evolution of the research area. Collaboration analysis of author collaboration network demonstrates several separate communities of researchers with ties between clusters, but no one predominant structure of collaboration. The institutional network is relatively compact; engineering-focused departments play significant role in forming research collaboration groups. However, the country network illustrates much wider international collaboration, where India, China, United Kingdom and United States are the main players with ties to many other countries. The findings indicate that the research area of Digital Twin in sustainable energy is internationally spread, but remains structured around quite specialized research groups and institutions. The increase in inter-institutional collaboration might be helpful for the integration of competences in engineering, artificial intelligence, energy policy and sustainability research, but it cannot be concluded based only on bibliometric evidence.

D. CONCLUSION

This work shows that research on the application of Digital Twins for sustainable energy is an emerging multi-disciplinary area that focuses on integration of digital technologies with the management, optimization, and use of renewable energy sources within the energy-system. From the results of bibliometric analysis, it can be seen that the main themes in research are digital twin, energy systems, energy management, energy efficiency, and optimization. From the results of temporal analysis, it becomes clear that an increasing interest in machine learning, deep learning, prediction, forecasting, predictive maintenance, and predictive control systems is observed. Moreover, increasing attention to renewable energy and its applications such as solar and wind power, as well as digital storage and battery charging, is shown. Citation analysis supports the significance of research in smart grids, integrated energy system scheduling, Digital Twin architecture, and AI-enabled energy optimization. However, collaboration analysis shows that there is a globally distributed research area with many author networks, institutional networks, and countries.

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