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Review

Smart and Sustainable Energy Consumption: A Bibliometric Review and Visualization

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Abstract: This paper presents a comprehensive bibliometric review and visualization of smart and sustainable energy consumption, delving into the challenges and opportunities of developing renewable and non-renewable energy sources. The study examines research trends and emerging themes about integrating smart solutions and sustainable energy resource consumption. The analytical methods used involve thoroughly analyzing empirical data, case studies, and review papers to map the research landscape. The results highlight dominant research topics, influential authors, and publication timelines in this field. The review identifies the key challenges in harnessing renewable and non-renewable energy sources, including the need for reliable energy sources, energy storage systems, and smart grid technologies. The paper concludes with insights into the most effective practices for promoting smart and energy-efficient methods while emphasizing the complexity of sustainable energy solutions.

Keywords: smart energy; sustainable energy consumption; energy efficiency; renewable energy; smart grid; bibliometric review; energy infrastructure; green technologies

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1. Introduction

Green or renewable energy is perpetually available through natural processes such as hydroelectricity, solar, wind, and tidal energy. These energy resources have minimal environmental impact, making them an attractive option for businesses and academicians seeking to reduce our reliance on fossil fuels and contribute to developing a cleaner, more sustainable energy future [1]. However, compared to fossil energy, the specificity of these energies is automatically recycled in nature [2]. There is a counterargument that renewable energy consumption may not be as environmentally friendly as it appears due to its reliance on scarce earth metals and its carbon footprint during energy manufacturing and production processes [3]. It is worth considering that non-renewable energy resources are more reliable and consistent, making them a better choice for meeting energy demands in emergencies [4]. Due to their high upfront costs and intermittent energy output, there is a claim that renewable energy sources are not economically feasible or sustainable in the long term [5]. The global focus has shifted towards developing a sustainable energy infrastructure to tackle climate change and growing energy demands. This shift is driven by a need to reduce carbon emissions and increase the use of renewable energy sources. Policymakers and businesses are investing in new technologies and infrastructure to support this trend.

There are many challenges in harnessing electricity from renewable or non-renewable sources, and it is essential to recognize that the end users must use the energy fed into the grid from the generation side in real time [6,7]. It is important to note that energy consumption constantly changes, meaning that power generation must always keep up with the demand. Due to varying consumption patterns, the network may face unexpected and significant requirements that could lead to insufficient energy supply or excess energy production and redirection [8]. The development of energy storage systems is currently in progress, but addressing the capacity maintenance of such large-scale systems remains challenging [9]. Khazali et al. [10] introduced a powerful strategy for maximizing the potential of combined wind and storage units in day-ahead nodal energy markets. Information gap decision theory (IGDT) was implemented to manage the uncertainties caused by wind generation and the price uncertainty of the system. An integrated approach was proposed to manage profit distribution for a wind storage system, including a risk-averse decision-making framework and various risk measurements such as the Conditional Value at Risk (CVaR), Value at Risk (VaR), and Shortfall Probability (SP) [11].

One key challenge remains the need for a practical approach to clarifying and refining the academic practice of conducting literature reviews [12]. Studies must demonstrate how smart and green technologies contribute to promoting sustainable energy consumption. However, there is still room for improvement in this area, as it can be awkward to compare policy frameworks and regulatory approaches designed to support the development of smart and sustainable energy programs.

Still, how best to reduce electricity consumption and establish a sustainable energy supply needs to be clarified. These include optimizing energy efficiency, using smart energy systems, and implementing smart solutions [13]. However, it is essential to combine these methods, as using them in isolation will lead to failure. Smart energy involves developing technologies for sustainable generation, transportation, and the consumption of electricity within the distribution system [14]. The future of sustainable energy lies in renewable resources, which are continuously replenished by nature without human intervention [15]. However, renewable energy sources cannot maintain stable energy levels during production, so fossil-fueled power plants are needed for consistency [16].

Considering the features above, a pressing need arises to evaluate the varying research perspectives that aid in comprehending the most effective ways to facilitate smart and energy-efficient practices. Two fundamental research questions guide the current research. The first question (RQ1) seeks to identify the factors enabling smart and sustainable energy consumption development. The second (RQ2) explores the contextual approaches, methodologies, frameworks, and tools that can facilitate the integration of smart solutions and the sustainable consumption of energy resources.

A bibliometric review is a powerful and insightful tool for analyzing current research trends, identifying existing gaps, and gaining valuable insights for future research endeavors. Previously, a scientific review was conducted to assess the current progress of Smart Energy Meters (SEMs) alongside other metering technologies such as Smart Gas (SG), Smart Heat (SH), and Smart Electricity (SE) meters [17]. Izam et al. [18] presented perspectives regarding solar energy technologies, focusing on photovoltaic (PV) systems. Additionally, their study encompassed a comprehensive review of the literature about the performance of solar energy technology to discern prevailing global trends in the adoption of solar energy for sustainable development. Some professionals have systematically analyzed the interconnections between smart grid technologies, energy storage capabilities, infrastructure expansion, and their integration within residential settings [19]. We thoroughly searched and assessed the extensive body of literature on smart and sustainable energy consumption. Our approach included examining empirical studies, case studies, and review papers. In contrast to other reviews, our visualization analysis enables us to discern patterns, trends, and gaps in the literature, offering a comprehensive and lucid view of the research field.

Section 2 presents the materials and methodologies employed in this study. When coupled with visualization analyses, this provides a comprehensive portrayal of the research landscape, highlighting the diverse perspectives and approaches researchers across various fields adopt in their exploration of future energy consumption. We thoroughly evaluated a wealth of published evidence, including empirical evidence, case studies, and review papers. In Section 3, our analysis identified dominant research topics, influential authors, publication timelines, and emerging research themes. This paper discusses and underscores (Section 4) the importance of comprehending the multifaceted complexity of sustainable and smart energy consumption solutions by combining systematic bibliometric review and visualization techniques with suggestions and limitations.

2. Materials and Methods

As Scopus is a popular source for literature searches it was chosen as the database for this study [20]. Scopus content is recommended as it can differentiate between publications by authors with the same name due to its filtering and indexing techniques. Scopus tools provide much broader and more comprehensive content coverage than similar competitors (Web of Science, PubMed) [21]. Furthermore, as a bibliometric database, Scopus provides free access to author and source information, including metrics [22].

A systematic literature network analysis (SLNA) was used to select and evaluate the literature. This approach consists of two main components (Figure 1). First, a systematic literature review (SLR) is conducted, followed by a bibliographic network and visualization data analysis. Keyword Co-occurrence Network (CONK) and Burst Detection analyses, after examining the Global Citation Score (GCS) and Co-Couplings of key articles, allows for the identification of emerging research directions.

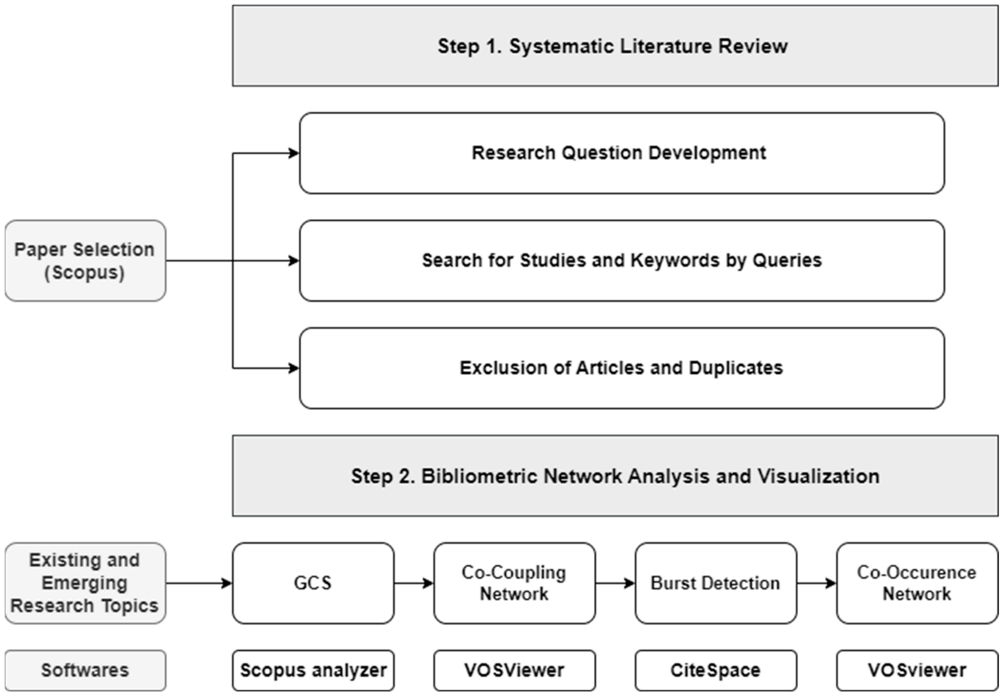

Figure 1. The research framework of the bibliometric review.

Based on the research questions identified in the introductory chapter, we conducted a keyword search of the literature on the research directions of smart and sustainable energy consumption. From a bibliographic research perspective, we first focused on building a query to consider the most appropriate publications. The query also included the different terms, synonyms, and expressions related to the keywords "smart", "sustain*", and "green" related to energy consumption. The following query command (TITLE) was applied to the publication titles, considering the above query terms: TITLE ((smart OR sustain* OR green) AND energy AND consumption).

The first search returned 1545 documents from between 1997 and 2024. For further analysis, only English-language articles were included in the query. The outcome included articles (61.8%), conference papers (28.7%), book chapters (4.2%), reviews (3.1%), erratum

(1.3%), and others (e.g., editorials, notes, retracted, data papers, and books) published by the press, respectively.

The data were cleansed of duplicates, second or multiple copies published by authors with the same title but in distinct sources (e.g., preprints, conference proceedings). We also excluded sources where the authors could not be identified. The remaining number of sources was 1527 in total.

The analysis included a review of the most cited literature on smart and sustainable energy consumption using the Global Citation Score (GCS), a normalized bibliometric tool provided by Scopus. As a first step, this methodology can provide insight into identifying leading experts and networks of collaboration in the field [23]. Subsequently, CiteSpace (version 6.2.R6) can identify and visualize key trends and transitions in the literature [24]. CiteSpace is designed to identify seminal research that has fundamentally impacted the growth of a particular scientific discipline or body of knowledge. The open access software package VOSviewer (version 1.6.20) provides almost unlimited analysis possibilities for bibliometric mapping and the visualization of data downloaded from Scopus and other databases [25].

3. Results of Bibliographic Network Analyses and Visualizations

3.1. Global Citation Score (GCS) Analysis

A GCS analysis can identify studies of emerging importance. The GCS value is the total number of citations received by a given publication across the entire Scopus database, and the normalized GCS is used to classify papers based on their last cited year (2023) and the number of years since their acceptance in Scopus [26]. This type of bibliometric analysis is used to identify the most cited and published papers since their first publication in the scientific community (Table 1) and to rank (TOP10) the most cited promising new papers in the field.

Table 1. Top 10 most cited articles, ranked by normalized GCS *.

Rank	Title(s)	Pub. Year	References	GCS	GCS *
1	Endorsing sustainable development in BRICS: The role of technological innovation	2023	[27]	200	200.0
2	Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid	2010	[28]	2281	162.9
3	Alternative energy and natural resources in determining environmental sustainability: a look at the role of government final consumption expenditures in France	2023	[29]	137	137.0
4	Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence	2021	[3]	284	94.7
5	Do renewable energy consumption and financial globalization contribute to ecological sustainability in newly industrialized countries?	2022	[30]	185	92.5
6	The role of renewable energy consumption and financial development in environmental sustainability: implications for the Nordic Countries	2023	[31]	90	90.0
7	Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development	2022	[32]	176	88.0
8	Clean energy consumption, economic growth, and environmental sustainability: What is the role of economic policy uncertainty?	2022	[33]	174	87.0
9	Unleashing the dynamic impact of the tourism industry on energy consumption, economic output, and environmental quality in China: A way forward towards environmental sustainability	2023	[34]	83	83.0
10	Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CO_2) in G-7 nations	2021	[35]	245	81.7

* Based on the top three most cited articles of each cluster.

Various aspects of sustainable development, renewable energy consumption, economic growth, and environmental sustainability in different contexts are covered by the top 10 research papers. The first investigates the interaction (positive) effects of technological innovation, renewable energy consumption, and natural resources on limiting CO_2 emissions in BRICS countries to contribute to the 13th Sustainable Development Goal (SDG) of taking urgent action to combat climate change and its impacts [27]. Alternative and nuclear energy, natural resources, and the final consumption expenditure of the government are uncertain and have a negative link with CO_2 emissions [29]. While economic growth increases our Ecological Footprint (EF), financial globalization and the renewable energies positively impact environmental quality [30]. Meanwhile, democracy and environmental regulations reduce EFs, contributing to ecological sustainability [32]. Nevertheless, Mohsenian-Rad et al. [28] proposed a game-theoretic approach to manage energy consumption among users in a smart grid to minimize energy costs while preserving user privacy.

3.2. Bibliometric Co-Coupling Network (CCN) Analysis

The CCN analysis complements previous studies by showing the networks of the most cited publications. A bibliometric coupling link is a connection or relationship between two elements, such as the links between publications, co-authorship, and co-occurrences between researchers and terms.

A Co-Coupling Network Map (Figure 2) of the most cited studies contains one type and one pair of links between two items. Each pair of links has a positive value. The higher the value is, the stronger the link is. The number of pairs of cited references in the same match equals the number of bibliographic coupling links between two documents.

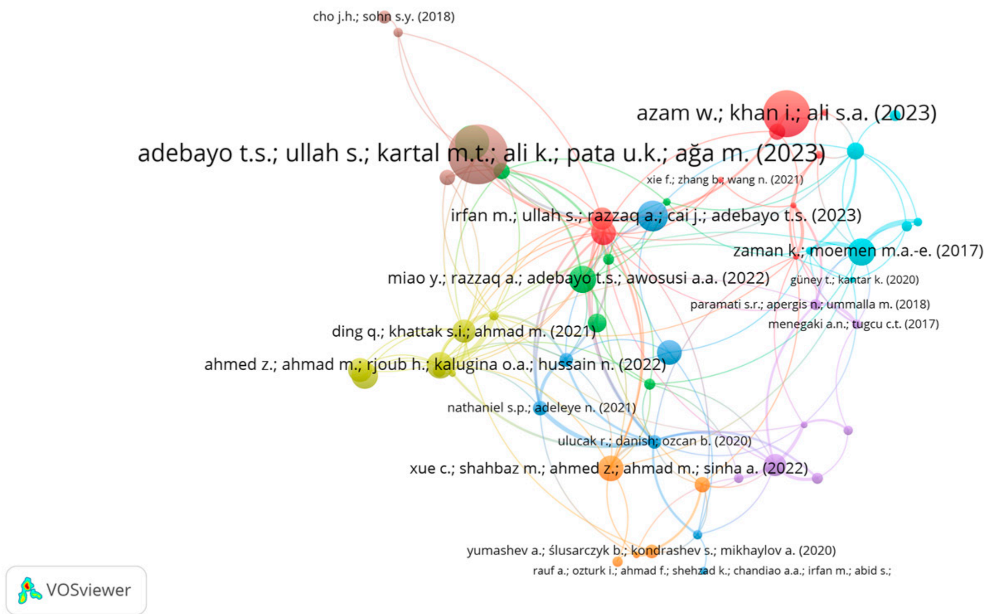

Figure 2. Co-Coupling Network Map (network visualization).

In this case, the construction of the network is from the level of individual documents to the aggregate level. Standardized citation weights are used to correct the fact that older documents have had more time to be cited than more recent ones. The normalized citation count of a document is equal to its number of citations divided by the average number of citations of all documents published in the same year and included in the data [36]. The higher the citation value, the bigger the size of the node.

The articles published on the given topic were divided into eight clusters (see Table 2). The top 3 cited articles in each cluster were considered in detail based on the CCN analysis.

Table 2. Results of the CCN cluster analysis *.

Clusters	Author(s)	References	Citations	Pub. Year
1	Khan, I.; Zakari, A.; Ahmad, M.; Irfan, M.; Hou, F	[37]	131	2022
	Wang, R.; Usman, M.; Radulescu, M.; Cifuentes-Faura, J.; Balsalobre-Lorente, D.	[38]	58	2023
	Bibi, A.; Zhang, X.; Umar, M.	[39]	50	2021
2	Miao, Y.; Razzaq, A.; Adebayo, T.S.; Awosusi, A.A.	[30]	163	2022
	Adebayo, T.S	[40]	87	2022
	He, Y.; Li, X.; Huang, P.; Wang, J.	[41]	57	2022
3	Mughal, N.; Arif, A.; Jain, V.; Chupradit, S.; Shabbir, M.S.; Ramos-Meza, C.S.; Zhanbayev, R.	[42]	148	2022
	Ulucak, R.; Danish; Ozcan, B.	[43]	144	2020
	Nathaniel, S.P.; Adeleye, N.	[44]	132	2021
4	Ding, Q.; Khattak, S.I.; Ahmad, M.	[35]	235	2021
	Ahmed, Z.; Ahmad, M.; Rjoub, H.; Kalugina, O.A.; Hussain, N.	[32]	162	2022
	Zafar, M.W.; Saeed, A.; Zaidi, S.A.H.; Waheed, A.	[45]	76	2021
5	Saint Akadiri, S.; Alola, A.A.; Akadiri, A.C.; Alola, U.V.	[46]	227	2019
	Paramati, S.R.; Apergis, N.; Ummalla, M	[47]	86	2018
	Zaharia, A.; Diaconeasa, M.C.; Brad, L.; Lădaru, G.R.; Ioanăs, C.	[48]	58	2019
6	Zaman, K.; Moemen, M.A. el	[49]	288	2017
	Rehman, A.; Ma, H.; Ozturk, I.; Ulucak, R	[50]	93	2022
	Anser, M.K.; Usman, M.; Godil, D.I.; Shabbir, M.S.; Sharif, A.; Tabash, M.I.; Lopez, L.B.	[51]	62	2021
7	Xue, C.; Shahbaz, M.; Ahmed, Z.; Ahmad, M.; Sinha, A.	[33]	156	2022
	Vasylieva, T.; Lyulyov, O.; Bilan, Y.; Streimikiene, D.	[52]	146	2019
	Qudrat-Ullah, H.; Nevo, C.M.	[53]	53	2021
8	Adebayo, T.S.; Ullah, S.; Kartal, M.T.; Ali, K.; Pata, U.K.; Ağa, M.	[27]	165	2023
	Ikram, M.; Zhang, Q.; Sroufe, R.; Shah, S.Z.A.	[54]	158	2020
	Jiang, Z.; Lyu, P.; Ye, L.; Zhou, Y.W.	[55]	95	2020

* Based on the top 3 most cited articles of each cluster.

In the *first* cluster, articles present research findings and insights on the relationship between energy transitions, energy consumption, and environmental sustainability from different aspects and regions. The focus is on OECD countries [37], European developing countries [38], and the United States [39]. The papers highlight the complex interplay between energy consumption, technological innovation, economic development, and environmental sustainability. The focus is on the importance of sustainable energy practices and technological innovation for mitigating environmental degradation and promoting long-term environmental sustainability.

The research in the *second* cluster clarifies the required magnitude of renewable energy consumption, political stability, financial globalization, and other factors in achieving environmental sustainability in particular countries. Insights into the relationships between energy use, economic growth, and environmental degradation provide valuable information for stakeholders addressing environmental challenges [30,40,41].

The *third* cluster underlines the intricacy of the relationship between energy consumption and environmental sustainability [42]. These studies highlight the importance of introducing renewable energy, using resources sustainably [43], and adopting strategic policies to achieve long-term environmental protection and sustainable development at regional and global levels [44].

The documents in the *fourth* cluster look at different aspects of the relationship between natural resources, the consumption of renewable energy, the quality of the environment, and sustainable development. These studies provide valuable insights into the complex dynamics between energy consumption, environmental quality, and the policies needed to achieve sustainable development objectives [32,45]. They provide insights for policymakers to address environmental challenges [35] effectively.

The relationship between renewable energy consumption, economic activities, and sustainable development is investigated in the *fifth* cluster. These studies highlight the positive long-term relationship between environmental sustainability, renewable energy consumption, and economic growth as causal relationships between renewable energy consumption and other growth determinants [46]. GHGs and GDP correlate with energy consumption, while female population growth and health spending do not [47,48].

The *sixth* cluster of studies examines the relationship between energy consumption, carbon dioxide (CO_2) emissions, and economic development and the implications for sustainable growth and environmental quality. These papers highlight the need for comprehensive policies and strategies to achieve sustainable growth while mitigating green degradation concerning energy consumption [49,50], and they stress the necessity of mitigating the negative impacts of global warming [51].

The *seventh* cluster explores how clean energy consumption relates to ecological sustainability and other factors. Some consider economic policy uncertainty (EPU) and explore how using clean energy affects CO_2 emissions, which drive economic growth [33]. Others accepted that weakening controls on corruption increases GHG emissions [52]. However, scholars claim that solving sustainability issues through emissions reduction is not currently a priority for inclusive development in Africa [53].

The final and *eighth* group of sources looks at different aspects of the relationship between the consumption of clean energy, economic growth, environmental sustainability, and policy uncertainties. These findings have the power to shape the way organizations make decisions and investments, leading to a reduction in CO_2 emissions and a boost in ecological sustainability [54]. The transformation of structure is of greater significance than the overall progress of energy innovation in driving economic growth and addressing energy consumption disparities [55].

3.3. Burst Detection Analysis (BDA)

The Burst Detection Analysis (BDA) seeks to identify research areas and progress patterns over time to reveal the dynamics of academic articles [56]. Figure 3 shows the top seven keywords of Kleinberg's Burst Detection algorithm's strongest citation bursts [57]. All word marks were converted to lowercase as part of the normalization process. End words were excluded, and periods and hyphens were removed from abbreviations and initials. The BDA lists the authors' keywords that indicate significant interest this topic between 1997 and 2024. The focus of scientific research has shifted from smart grid(s) to energy efficiency and demand side management (2012–2018). Importantly, keywords such as "energy consumption and scheduling" were frequent between 2013 and 2020. Environmental sustainability (strength: 4.86) and green building (4.30) are tied to the leading bursts in current years (2021–2024).

Figure 3. Author's top 7 keywords as result of burst * detection analysis from 1997 to 2024. * The most active (burst) research area is highlighted in red, followed by grey.

New technologies can enhance energy efficiency and reduce carbon footprints, creating more sustainable energy consumption aligned with environmental goals and economic objectives [58]. As advanced technologies are integrated into our lives, the possibilities for innovative progress are endless. Artificial intelligence (AI) is leading the charge in revolutionizing energy production and a wide range of industries [59]. The integration of AI and big data has the potential to enhance the precision of energy consumption dimensions, a crucial aspect for the success of smart grids. These advanced systems are designed to constantly monitor energy usage, minimize waste, and utilize machine learning to optimize consumption, reducing daily peaks [60].

Smart homes and green buildings are designed to reduce energy consumption and minimize environmental impact. Sustainable materials and green buildings meet present needs without sacrificing future generations. Green buildings are a proven solution to save energy and minimize water usage with their sustainable features [61]. Moreover, the smart city concept is an extension of smart homes, with optimization techniques implemented on a much larger scale to manage urban traffic, street lighting, and waste effectively [62].

3.4. Co-Occurrence Network of Keywords (CONK) Analysis

Figure 4 provides more detailed knowledge on the keywords and clusters generated by the CONK method. By default, we performed clustering based on the total strength of the citations, which normalizes the association between each element [63]. Clusters do not overlap, i.e., an item can only belong to one cluster. However, clusters do not have to cover all items. Therefore, there may be keywords that do not belong to any cluster. Serial numbers identify the clusters. This cluster analysis resulted in five different research topics. The co-occurrence of keywords in the dataset determines the order of the research topics.

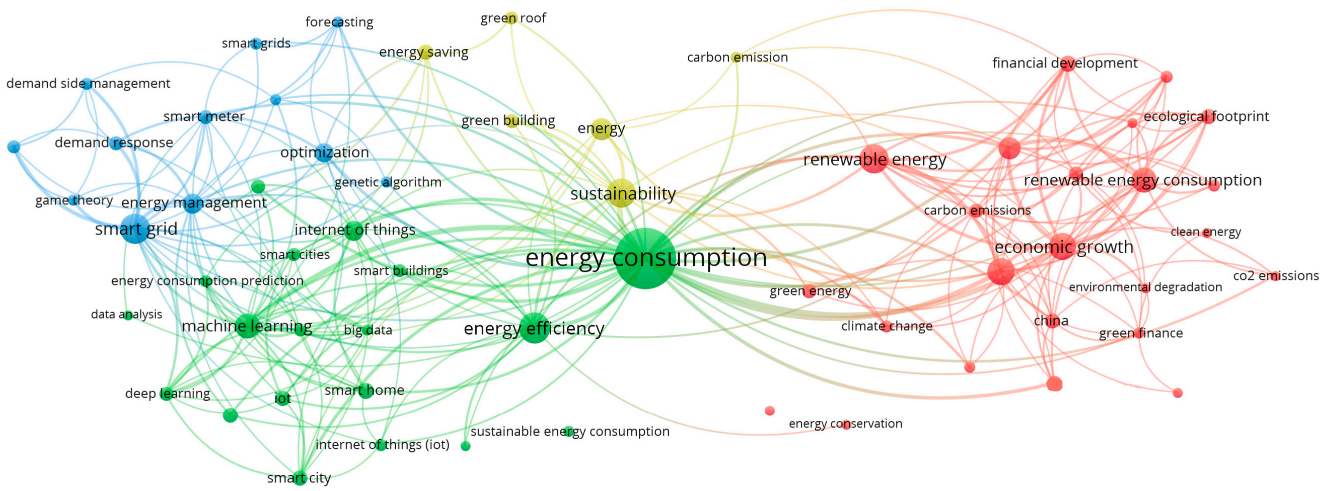

Figure 4. Co-occurrence network map of keywords.

Cluster 1 examines renewable energy's influence on economic advancement, sustainable development, and environmental stability. Adebayo et al. [27] indicated that technological advancements and using renewable energy can decrease CO_2 emissions, while utilizing natural resources can also aid in reducing emissions. Nevertheless, their research emphasizes the need for additional exploration of different factors related to environmental stability beyond CO_2 emissions and suggests comparing results from other regions. However, the study also noted the need for further investigation into the specific mechanisms and policies that can increase the use of renewable energy in the EU-28 countries to maximize their impact on economic growth and environmental sustainability.

Cluster 2 is focused on developing smart grid technologies to optimize energy management, demand response, and forecasting. There are three primary energy management strategies for smart homes, for instance, (1) DA-GA, (2) DA-Game Theory, and (3) DA-

GmEDE. Hafeez et al. [64] conducted a study to investigate the impact of these strategies on electricity billing and peak-to-average rates (PARs) when home appliances are scheduled in response to price signals predicted for the day. The results indicated that the DA-GmEDE strategy particularly effectively reduces PARs and costs. Furthermore, the role of smart cities and the importance of integrating socio-behavioral factors into adopting smart technologies is emphasized. A broader consideration of technological innovations and social dynamics is necessary to promote smart city benefits such as social inclusion and security. Their study highlights the need for more inclusive research considering multiple significant factors [65].

Cluster 3 focuses on applying machine learning, deep learning, Internet of Things (IoT) technologies, and big data analytics in the context of smart cities and buildings. Divina et al. [66] implied that machine learning models, especially ensemble techniques and neural networks, are more effective in predicting energy consumption patterns than traditional statistical methods. Pham et al. [67] demonstrated that particle swarm optimization and genetic algorithms can substantially improve energy efficiency and user satisfaction in dynamic pricing systems in smart grids. Meanwhile, Muralidhara et al. [68] showed that support vector machines and neural networks can more accurately predict energy consumption, leading to more efficient energy management and planning for building energy requirements. Imran et al. [69] introduced a predictive control system for optimizing thermal comfort and energy consumption in residential buildings, significantly reducing energy usage and improving living comfort. IoT-based climate control systems for smart greenhouses also reduced energy consumption compared to traditional systems while optimizing conditions for crop cultivation [70].

Cluster 4 focuses on mitigating the impact of global warming by promoting energy efficiency, green energy sources, energy saving, and sustainable consumption. A study in France from 1987 to 2019 examined the effects of clean energy consumption on CO_2 emissions, considering factors such as urbanization and economic growth, and found that economic policy uncertainty (EPU) and economic growth increase emissions and that urbanization supports environmental quality [33]. Furthermore, the efficiency of coal utilization and the uncertainty surrounding climate policies can reduce CO_2 emissions by various rates and over an extended period. Additionally, the consumption of green energy and the implementation of green innovations have been shown to enhance ecological quality by reducing CO_2 emissions in the short-to-medium term [71]. This research delves into strategies to reduce energy consumption and CO_2 emissions in different neighborhoods, focusing on the role of renewable energy and efficient building designs.

Moreover, significant improvements can be achieved through technological and policy adaptations by 2050 [72]. Furthermore, for optimizing energy consumption and data transmission predisposed to delay in clustered wireless sensor networks (WSNs), a new algorithm was invented that minimizes energy use while ensuring efficient data handling [73]. However, there remains a gap in our understanding of the real-world application and scalability of the proposed algorithm in diverse operational environments, such as different types of IoT applications.

Cluster 5 focuses on sustainable architectural solutions, such as green roofs and energy-saving technologies, to reduce energy consumption. Kirikkaleli and Adebayo [3] analyzed the impact of financial development and renewable energy consumption on environmental sustainability globally, using advanced econometric methods. The results revealed a significant long-term positive effect of both financial development and renewable energy on environmental sustainability, suggesting that global policies should promote these factors to enhance environmental quality. Ulucak et al. [43] delved into the impact of renewable and non-renewable energy consumption, GDP per capita, and natural resource rents on environmental degradation across OECD countries. Their econometric models, incorporating the Environmental Kuznets Curve (EKC) hypothesis, tested these relationships and found that environmental degradation can decrease when per capita income reaches a threshold level. Additionally, Yumashev et al. explored the influence of energy consumption, the

Human Development Index (HDI), and environmental factors on sustainable development. The utilization of the three-stage least squares (3SLS) method offered insights into the impact of renewable energy sources on economic conditions and sustainable development levels, highlighting the intricate interplay among these factors and the HDI [74].

4. Discussion and Conclusions

This study provides a comprehensive bibliometric review and visualization of smart and sustainable energy consumption, addressing the challenges and opportunities in developing renewable and non-renewable energy sources. The study methodically examines research trends and emerging themes and integrates intelligent solutions for sustainable energy resource consumption.

The findings of this study align with previous reviews [75,76], highlighting the intricate and multifaceted process of transitioning to sustainable energy consumption. The results of this study underscore the importance of incorporating smart technologies and implementing efficient energy management practices. Furthermore, identifying critical research areas and influential works serves as a guide for future studies and illustrates potential opportunities for collaboration.

Several dominant areas that contribute to developing smart energy consumption behavior, load forecasting, and smart grid technologies have been identified. There is a clear trend towards incorporating the Internet of Things (IoT) for improved energy management. In addition, this review maps the contributions of leading researchers and tracks publication trends over recent decades, highlighting pivotal works that have shaped the current landscape.

Despite the benefits of sustainable energy programs, some challenges and limitations must be addressed. Ongoing support and a continuous energy supply are essential, and efficient storage solutions are crucial for balancing supply and demand, especially for renewable energy sources. Advancements in smart grid infrastructure are necessary for integrating renewable energy and enhancing our overall energy efficiency.

Energy optimization means achieving the same output with less energy consumption [77]. It can be accomplished using energy-efficient technologies, such as LED lighting or more efficient heating and cooling systems. By adopting these energy-saving measures, businesses and individuals can significantly reduce their energy consumption and costs [78]. By deploying intelligent grid systems, the real-time monitoring of energy consumption data is enabled, allowing for prompt interventions to minimize energy usage [79]. Developing more sophisticated and enduring energy consumption practices is not solely a technological challenge but also a necessary reaction to imminent environmental issues. Intense population growth has been an ongoing trend and is expected to continue in the foreseeable future. As a result, there will be an increasing demand for industrial production, which in turn will lead to an amplified reliance on natural resources [80]. It is crucial to recognize that the long-term viability of industrial production and economic growth hinges on balancing resource needs and preserving natural ecosystems [81].

The integration of smart infrastructure and IoT is revolutionizing energy optimization, and the smart home is emerging as a leading example of this trend. IoT devices, including advanced sensors, are deployed throughout homes to capture, store, and analyze real-time data [82]. These data are then leveraged to optimize energy usage and improve overall efficiency. The data collected from smart homes are routed to a central processing unit which can intervene in the processes of the home. The development of such smart homes serves to mitigate energy consumption in urban settings [83]. Improved data management enables the better monitoring of carbon emissions, providing a clearer picture of their ecological impact [84].

The concept of smart cities is closely associated with the rise of Artificial Neural Networks (ANNs). Bourhnane et al. [85] have described a model for predicting the energy consumption of appliances in a smart grid. This model is part of a larger research project to improve energy management systems in smart grids, utilizing various technological tools such as machine learning and renewable energy sources. The ANN model is designed to assist in planning and optimizing energy use efficiently across different devices and periods. The authors emphasize that while existing models for predicting and timing energy consumption exist, they often only perform well on limited datasets and may not be applicable in real-world situations.

Their research suggests that decision-makers may need to fully consider diverse cultural and economic factors, which can greatly affect the effectiveness of sustainable energy initiatives. It also points out a potential oversight of technological and infrastructural limitations in various regions. In addition, critics argue that these studies fail to adequately consider the long-term environmental and social impacts of implementing these technologies, particularly regarding resource consumption and waste management [86].

There are several limitations to this study. First, the results of bibliometric analyses can vary depending on the chosen database. Second, the limited access to certain documents excluded critical writings that could be valuable for future researchers studying the subject. Research should focus on the advancement of affordable and high-capacity energy storage systems. Additionally, exploring smart grid technologies to improve their reliability and efficiency is advised. Further exploration of utilizing IoT and big data for predictive maintenance and real-time energy management is also warranted.

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