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MAPPING THE LANDSCAPE OF SMART ENERGY SYSTEMS (SES): INSIGHTS FROM BIBLIOMETRIC AND STATISTIC ANALYSIS FOR ENVIRONMENTAL MANAGEMENT

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Purpose: The objective of the article is to map the global research landscape on Smart Energy Systems (SES) between 2020 and 2024 by identifying dominant scientific trends, thematic clusters, collaboration networks, and emerging research topics.
Design/methodology/approach: The research employs a quantitative design, combining bibliometric analysis and statistical methods. A total of 11,609 publications were retrieved from the Scopus database, focusing on SES-related keywords. Bibliometric mapping using VOSviewer was conducted to analyze keyword co-occurrences, country collaborations, and author networks. Statistical visualization, including bag plots, was used to identify outliers and trends in keyword usage, highlighting both prevalent and emergent areas of research.
Findings: The analysis revealed six major clusters of SES research, including smart power grids, renewable energy integration, energy management systems, optimization techniques, and emerging digital technologies like IoT and blockchain. Dominant keywords included "smart power grids" (3572 occurrences), "electric power transmission networks" (2856), and "renewable energy resources" (1629). Outlier analysis indicated that future directions in SES research are closely linked to blockchain, machine learning, and green hydrogen.
Research limitations/implications: The study offers actionable insights for policy-makers, business leaders, and industrial stakeholders. Policymakers should prioritize regulatory frameworks promoting digitalization and interoperability of energy systems. Industry actors are encouraged to invest in IoT-enabled energy infrastructure, AI-powered decision-making tools, and peer-to-peer energy platforms. SES development is also strategically relevant for national climate goals, economic modernization, and industrial decarbonization.
Originality/value This paper is the first to offer a cross-sectional, global bibliometric and statistical mapping of Smart Energy Systems research in the post-COVID-19 era (2020-2024). It goes beyond traditional bibliometric studies by integrating quantitative visual analytics (bag plots) to reveal latent structures and trends. The article also introduces a typology of emergent research areas and provides practical guidance for aligning SES innovation with environmental and industrial policies.
Keywords: smart energy systems (SES); bibliometric analysis; renewable energy sources (RES).
Category of the paper: research paper.

1. Introduction

Advancements in areas such as artificial intelligence, blockchain, and the Internet of Things (IoT) are opening new opportunities in energy systems, creating Smart Energy Systems (SES). Intelligent electric grids rely on advanced technologies such as monitoring and control systems, sensors, smart meters, energy management systems, and advanced data analysis algorithms (Mohammadi et al., 2018). The collection, processing, and analysis of this data allow for a better understanding and control of the power system. Intelligent electric grids offer many benefits for consumers, grid operators, and society as a whole. Primarily, they enable better utilization of available energy resources through the optimization of distribution and the use of renewable energy sources (Dincer, Acar, 2017). Thanks to the ability for bidirectional energy flow, consumers have the opportunity to both draw energy from the grid and feed excess energy back into the grid, thus improving energy efficiency (Anjana, Shaji, 2017; Crossley, Beviz, 2010). There is an increase in consumer engagement in producing renewable energy. New forms of consumer energy initiatives are emerging in the market, such as energy cooperatives (Gajdzik et al., 2024a). In the global climate policy, solutions in SES can be used in strategies of industrial decarbonization based on renewable energy sources (RES) and universal access to energy (Nagaj et al., 2024; Razmjoo et al., 2022; Gajdzik et al., 2024b, Kvasničková et al., 2023). Development of the SES requires broad cooperation (partnership) at many levels of economies, industries and societies (Zhou et al., 2025).

The management of variable renewable energy sources, energy conservation, and renewable energy sources are receiving an increasing amount of attention. Although significant emphasis should be made on encouraging power savings, integrating variable renewable energy sources into the electrical grid in order to reduce emissions is receiving more attention (Ryu et al., 2014; Mason et al., 2010; Khalid, 2024; Elliston et al., 2012; Krajačić et al., 2011).The rising need for smart energy systems originates from the growing acceptance of renewable energy sources, growing consciousness around energy conservation, and the anticipated rise in energy expenses and waste (Xu et al., 2020; Gajdzik et al., 2023d, 2024c; Gajdzik et al., 2025). Numerous studies exist on the bibliometric analysis of the smart energy system issue, but they typically focus on a specific country (Wang et al., 2020; Gajdzik et al., 2023b), management innovations within the smart energy system domain (Ali et al., 2021; Wang et al., 2022), or renewable energy systems (Rosokhata et al., 2021; Ionescu et al., 2022; Gajdzik et al., 2024b; Lund et al., 2017; Pan et al., 2023; Edgar, Pistikopoulos, 2018). In management, the emphasis is primarily on the application of intelligent technologies to the autonomous optimization of industrial processes, especially in highly energy-intensive industries (Gajdzik et al., 2021).

The primary goal of this paper is to provide a comprehensive analysis of the current state and emerging trends in research related to Smart Energy Systems (SES). The paper aims achieving following objectives:

- To elucidate the structure and dynamics of the SES research field, including key research clusters, as well as mapping their components to understand the SES in global space.
- To highlight emerging trends and significant developments within the SES domain. This includes analyzing keyword patterns and research focus areas to pinpoint novel concepts, innovative technologies, and evolving methodologies that are shaping the future of energy systems.

Authors analyzed data from 2020-2024: bibliometric analysis. The academic website Scopus was main source of scientific publications in authors' research in smart energy systems (SMS). 11,609 research publications published between 2020 and 2024 have been included in our analysis. The title, abstract, and keywords sections provide search materials related to the "smart", "energy", and "systems" topics. Using a content analysis, we looked at the most frequently used terms and their associations in order to show the structure of the scientific area. A network of co-occurrences was further considered. VOSviewer was used to carry out the analysis. Results of this analysis were cooperation networks and keywords clusters for two scopes of analysis. First scope for 128 keywords and second for 87 keywords. Moreover, the results of Scopus database analysis was used as a basis of statistical analysis using bag plots. To investigate the important data that the world's clouds provide in order to address the following primary research questions (RQs):

- RQ1 - What are the key scientific trends, concepts, and thematic clusters in the global research landscape on Smart Energy Systems (SES) between 2020 and 2024?
- RQ2 - What are the emerging topics and outlier keywords that descriptive directions of SES research in the Scopus database between 2020 and 2024?

2. Literature review

The term "Smart energy system" (SES) is contend with smart energy and it is a part of sustainable energy systems. The term "smart energy" originated from the term "smart earth" proposed by International Business Machines Corporation (IBM) in 2009 (Crossley, Beviz, 2010). The initial concept of sustainable energy systems was introduced by Lund, Andersen, Østergaard, Mathiesen, and Connolly (2012). They stated that, when considering the electricity sector as a component of a larger sustainable energy system, more cost-effective and better solutions for smart grid applications can be found than when considering the sector as a stand-alone entity. As a result, using a sustainable strategies rather than a smart grid approach that focuses just on power would be beneficial. This explanation was improved upon and revised as sustainable energy systems gained more attention in the paper (Lund, 2014) and (Lund et al., 2017). The concept of sustainable energy has emerged, encompassing the entire process related to energy, from sources of acquisition, through various types of power plants and methods of delivering energy to consumers, to issues related to its efficient management (Yang et al., 2010; Bossel, 2005).

Now about “smart” in SMS. Smart means Self-Monitoring, Analyzing, and Reporting Technology (Xu et al., 2020; Zhang et al., 2024). The goal of the Smart Energy System (SES) is to combine the transportation, heating, and electrical sectors with a range of storage options—whether hourly, daily, seasonal, or biannual—to provide the flexibility required to include significant penetrations of variable renewable energy (Koutra et al., 2018). SES is a whole, and therefore the overall efficiency of systems must be optimized through interconnections between systems and the capabilities of Fourth Industrial Revolution technologies (Koutra et al., 2018; Khatua, 2019; Wolniak et al., 2020, Zhu et al., 2022). These energy systems, in line with climate policy, must incorporate renewable energy sources (RES), but most renewable sources (e.g., solar and wind energy) are intermittent, and consumer energy demand also experiences significant fluctuations (Aghamolaei et al., 2018). Smart energy system is not simply a combination of various sources of energy and subsystems (infrastructure, data, information technology, IoT etc.) but is subject to complex interactions inside and outside. Global optimization and cross-sector integration of the whole energy system are highly prioritized in the sustainable development of economies and industries.

According to Lund et al. (2012) the term "Smart Energy Systems" has frequently been used interchangeably with "Smart Grid," particularly in the context of control management. It also denotes that the control system in question has applications extending beyond just the electricity sector. Lund et al. (2017) aim to recognize the concept of smart energy systems, which integrate multiple energy sectors to create a comprehensive strategy for sustainable energy solutions (Bibri et al., 2017). The construct of SES concept is a form of model for various sectors (transportation, industry, buildings, heating and cooling, as well as electricity). Based on a literature review, these authors conclude that current scientific knowledge indicates that solutions for integrating renewable energy are focused within the boundaries of energy subsectors, relying on concepts such as "smart grid", "zero-energy buildings", and "thermal energy". Meanwhile, the industrial sector and the heating and cooling sectors have largely been overlooked. These authors believe it is crucial to highlight in descriptions of smart energy systems the advantages of transitioning from a single-sector approach to integrating the entire system into ecosystem systems (Lund, 2014; Lund et al., 2012, 2017). The SES system is created by main system of energy production (centralized energy production, three major energy networks, energy hubs, energy-using departments, and energy storage) and system of infrastructures with tree pillars: smart grids, smart heat networks, and smart fuel networks. Energy hubs link energy networks and regional energy use, distribution, and storage (Lund et al., 2017). These solutions are supported by computer management systems and smart technologies. The system nodes are end-use energy sectors including construction, transportation, and industry in addition to all energy sources and energy networks.

Smart energy systems (SES) with data and information technology support are seen to be promising options for energy system integration (ESI) in order to achieve a low-carbon and sustainable energy transformation (Ionescu et al., 2022; Lund et al., 2012). Based on the principles of cross-sector integration and whole system optimization, SESs regard smart grids, smart heat networks, and smart fuel networks as the three pillars (Lund et al., 2017; Zheng et al., 2023). In order to optimize smart energy systems, Mohammad et al. (2018) presented the idea of an energy hub and examined its uses in a variety of contexts, including dwelling, business, and industry. Østergaard (2015) elaborated on advanced performance indicators and assessed the use of the Energy PLAN model in smart energy systems. Bahramara et al. (2016) addressed the equipment model and optimization process in her study of the HOMER model's use for optimizing renewable energy systems. After reviewing the use of the particle swarm optimization (PSO) and genetic algorithm (GA) in hybrid energy systems, Fadaee et al. (2012) found that these two optimization techniques were most often used in hybrid energy systems. Suganthi et al. (2015) examined the use of fuzzy logic in the optimization of several renewable energy subsystems and suggested appropriate fuzzy logic for each. Smart energy systems are increasingly based on microgrids. EU policy provides funding for microgrid projects (MORE MICROGRIDS project, CRODIS). Microgrids are modern distribution systems that can reduce emissions, improve power quality, and reduce the cost of heat and electricity supply. Energy conservation and its diversification is one of the main aspects of management.

In the context of management, Mbungu et al. (2020) investigate the application of smart metering technologies in the energy management system for residential microgrids. Smart grids contribute to reliability and security of energy supply. Thanks to the ability to monitor in real time and quickly detect failures, it is possible to react immediately and minimize disruptions to the power supply. In addition, intelligent energy management systems enable flexible load sharing and remote control of the grid, which contributes to a better balance in the electricity system. The authors propose a dynamic system that can maximize energy flow and guarantee efficient power supply through intelligent energy resource management. Such a system can also adapt to the functions and types of households in a given energy system. The authors (Mbungu et al. (2020) create a system that simulates a smart metering framework to gather information from various parts of the electrical system, such as energy storage and solar systems connected to the grid. To regulate energy flow based on demand response and energy prices, they proposed three optimal control scenarios utilizing linear and quadratic techniques. The research indicates that incorporating green hydrogen into intelligent energy systems may considerably enhance energy economy, minimize expenses, and diminish greenhouse gas emissions. According to the simulations, hydrogen has significant advantages for energy storage and the integration of renewable energy sources, improving the overall sustainability of community-scale energy systems. The research indicates that by optimizing the use of energy storage and solar systems, the proposed energy management system can significantly reduce energy costs and improve energy savings. The trial results confirm that the technology is reliable and effective in enhancing energy efficiency for residential applications. A smart energy system integrates many participants in the energy chain, from raw material suppliers and energy producers from various sources to consumers. In this integration, blockchain technology plays a helpful role by improving data and transaction management through applications such as peer-to-peer energy trading, grid enhancement, and electric vehicle support. Blockchain technology increases security, ensures better data privacy, data transparency, ubiquitous solutions, and greater data availability (Erturk, 2019). In order to create a synergistic in the SES, the system combines many sectors, including concentrated energy supply, industry, construction, and transportation (Md Shopan Ali et al., 2024).

Summary of the Literature Review on Smart Energy Systems (SES):

The literature on smart energy systems highlights several key areas:

- Focus on "Smart": This refers to the intelligence of the energy system, particularly its performance in terms of control, automation, and efficient management.
- Focus on "Energy": Emphasizes the use of renewable and diversified energy sources, aiming for a cleaner and more sustainable energy mix.
- Focus on "System": Highlights the integration of various subsystems into a unified structure. The core idea of a smart energy system is the seamless integration of multiple energy sectors, such as electricity, heating, and transportation.

The "smartness" of a smart energy system is primarily defined by the extent of system integration and the sophistication of its management processes. In the evolution of energy systems, SES represents the most advanced and holistic form.

3. Research methodology

In the manuscript we used the analysis of papers about SMS. Our research part of this manuscript consist of two part: bibliometric analysis and statistical analysis. The academic website Scopus was our main source of scientific publications, and we employed bibliometric analysis to identify the most relevant research in smart energy systems. 11,609 research publications published between 2020 and 2024 have been included in our analysis. The title, abstract, and keywords sections provide search materials related to the "smart", "energy", and "systems" topics. Our analysis consisted of two methods: the first stage – bibliometrics, the second stage – statistics. VOSviewer was used to carry out the bibliometric analysis. This computer program can create maps with numerous publications, maps with multiple items, maps of nations, publications, journal maps based on networks (co-citation). Moreover, it can create term maps based on common networks. In our analysis we used this program to present the co-authorship networks, keyword co-occurrence networks, and country collaboration networks, as well as to perform cluster analysis and visualize the structure of the scientific research landscape in smart energy systems. The 160 keywords were used. Bibliometric analysis consists of four steps. Step 1: Search criteria in Scopus database (get articles base on most citied and newest researcher for each keywords). Step 2: Data collection (export Scopus database to import in VOSviewer for further analysis). Step 3: Group categorising (classification and clustering related keywords in VOSviewer). Step 4: Interpretation of results for each networks of analyses. In the second part of our research about SES we used statistical analysis. The method consists of four steps: Step 1: Data Collection and Pre-processing. Step 2: Construction of bag plots. Step 3: Analysis of keyword occurrence and link strength. Step 4: Identification of outliers and emerging trends.

4. Results and discussion

Results of bibliometric analysis are presented in the forms of networks, which allowed to establish clusters in the studied areas. Figure 1 shows co-occurrence and all key words with a number of occurrences of keywords 200. During this stage of analysis, 128 all key words were generated. Figure 1 shows six clusters (color: green, blue, red, yellow, violet, azure). The dominant words in the blue cluster are the words Smart Power Grids, Electric Power Transmission, Renewable Energy Resources (RES). The green cluster is dominated by the words Energy Efficiency, Energy Utilization, Internet of Things. The red cluster is dominated by the words Renewable Energy with different sources according to climate policy. The yellow cluster is dominated by the words Optimization and Costs. The violet cluster is dominated by the words Energy Storage with different solutions. The azure cluster is dominated by the words Power Markets, Blockchain.

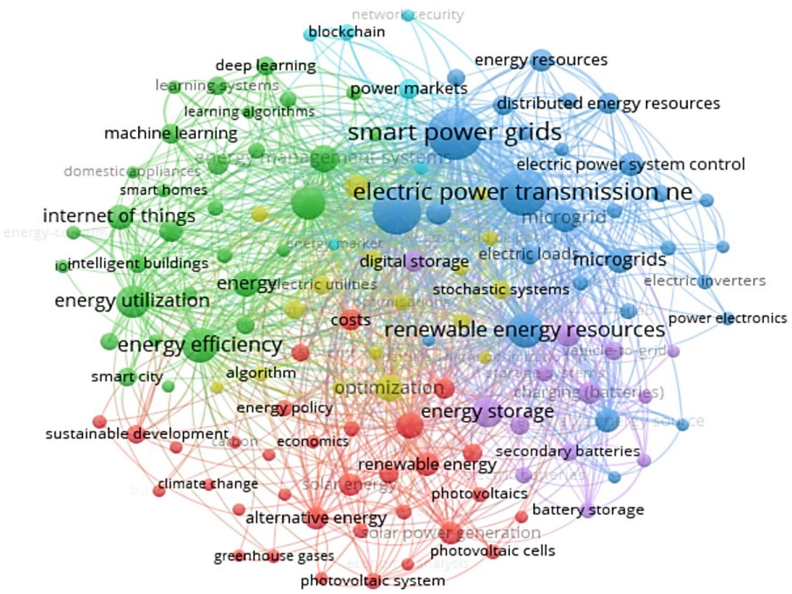

Figure 1. Word cloud for the co-occurrence - all key words (number of occurrence of keywords 50).
Source: own elaboration based on bibliometric analysis of papers in Scopus database.

Bigger words (Figure 1) stand out more in the visual depiction because they suggest a greater frequency of occurrence. "Smart Power Grids", "Energy Power Transmission", "Energy", "Energy storage", "Energy Efficiency", and renewable energy resources“ are among the most recognizable words. These phrases draw attention to the research's main areas of emphasis. Based on the analysis the key studies are "Smart Grids", "Renewable Energy", and "Energy Power Transmission." This graphic highlights a significant body of research on the integration of renewable energy sources in SES.

Figure 2 depicts a word cloud for co-occurrence, including author key words. Each word's magnitude in the cloud represents its frequency of occurrence as a keyword; bigger terms are more prevalent. The research's primary areas of concentration are highlighted by prominent phrases such as "Smart Grid", "Renewable Energy", "Energy Management", and "Energy Efficiency". A substantial amount of the word "Internet of Things (IoT)" also occurs, implying that IoT technologies are essential to the creation of smart energy systems. The word "optimization", which refers to initiatives meant to improve these systems' effectiveness and performance, is another crucial one. Clusters of similar terms, such as "Smart Grids", "Renewable Energy", "Energy Management", and “Demand Response” may be shown in the figure 2. The word cloud suggests that integrating renewable energy sources, effectively managing energy resources, and enhancing sustainability (demand response) are major areas of study interest. Fourth Industrial Revolution solutions such as IoT, Blockchain, machine learning and others are often mentioned by authors of papers in database Scopus, highlighting how crucial the use of new technologies is to their SMS development, with an emphasis on Smart Grids (two biggest words in the Figure 2, the higher occurrence of a word, the larger the font; accordingly, as their size reduces, frequencies of occurrence will fall).

When we deepen the bibliometric analysis, we notice that the key word “Smart Grid” is dominated by “Smart Power Grids” (Figure 3). The studies of authors are clustered around the two strongest determinants of SES, which are: “Smart Power Grids” and “Smart Grid”. These two keywords (main research areas) must take into account the requirements of “Energy Efficiency” and “Energy Management” (neighboring clusters), and “Energy Storage”.

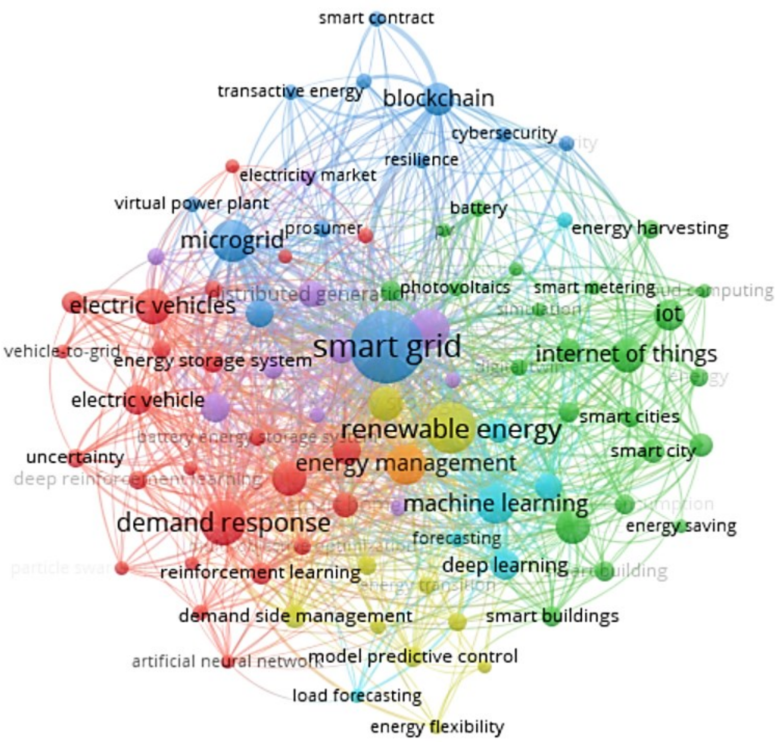

Figure 2. Word cloud for the co-occurrence - author key words (number of occurrence of keywords 50).
Source: own elaboration based on bibliometric analysis of papers in Scopus database.

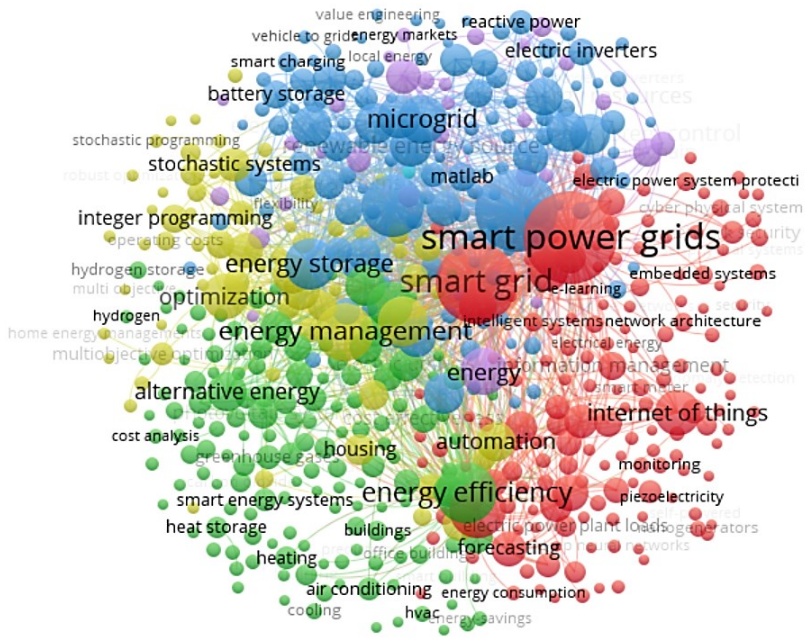

Figure 3. Word cloud for the co-occurrence - all key words (number of occurrence of keywords 50).
Source: own elaboration based on bibliometric analysis of papers in Scopus database.

At this stage, in order to provide a more detailed insight into the analysis, a statistical examination was conducted using bag plots. A bag plot is a visualization technique that illustrates the distribution of data points across various categories or groups. In this context, the plot facilitates the exploration of the relationship between two key metrics: total link strength and occurrence. The keyword "smart power grids" appears most frequently, with 3572 occurrences and a total link strength of 24,102 (Table 1). This indicates significant attention from researchers towards this cluster in the context of smart energy systems development. Following this, "electric power transmission networks" is the second most frequently used keyword, appearing 2856 times with a total link strength of 19,454. This reflects the critical importance of transmission networks in the discourse on smart energy systems. The keyword "smart grid" ranks third, occurring 2689 times with a total link strength of 18,871. This further underscores the centrality of smart grid technology in contemporary research on energy systems. Other notable keywords include "renewable energy resources" (1629 occurrences, 12,804 total link strength), "energy management" (1427 occurrences, 11,719 total link strength) (Table 1). Figure 4 presents a bag plot illustrating the relationship between total link strength and occurrence for all keywords from bibliometric analysis. In the table 1 are selected keywords for it.

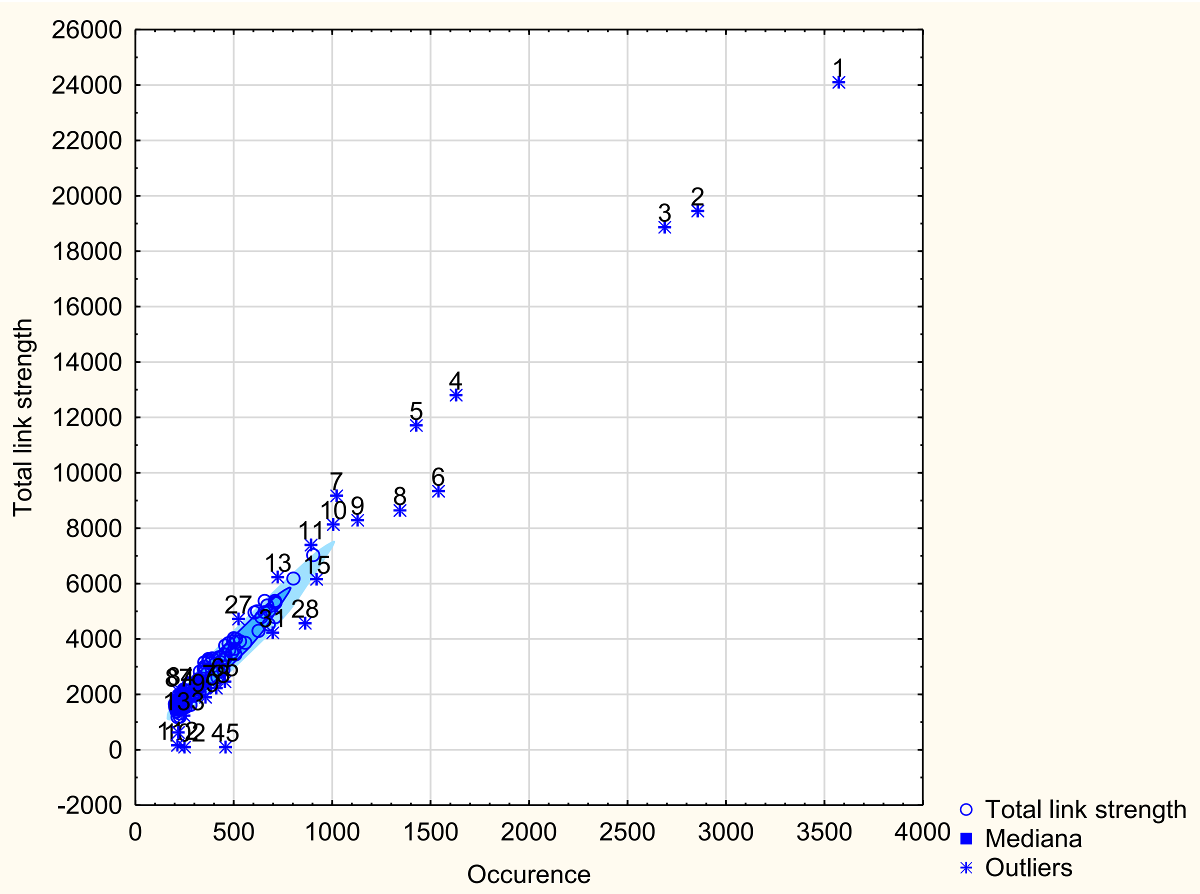

Figure 4. Bag plot – total link strength vs occurrence for all keywords.

Source: results of analysis by using computer programme (Statistica).

Table 1.
The of papers about Smart Energy System from Scopus according to keywords – selected keywords

Number	Key words	Occurrence	Total link strength
1	smart power grids	3572	24,102
2	electric power transmission networks	2856	194,54
3	smart grid	2689	18,871
4	renewable energy resources	1629	1,2804
5	energy management	1427	11,719
6	energy efficiency	1539	9337
7	energy management systems	1022	9174
8	energy utilization	1344	8643
9	energy storage	1129	8295
10	microgrids	1005	8133

By plotting total link strength against occurrence for all keywords, Figure 4 provides insights into the importance and prominence of various keywords within the dataset or context under study. The plot likely reveals patterns such as keywords that are highly linked but infrequently occurring, indicating their significance despite being less common. Conversely, keywords that are frequently occurring but have low link strength may suggest a lower level of importance within the dataset or context. In the bag plot depicting the relationship between occurrence and total link strength for keywords related to Smart Energy Systems, several patterns and insights can be discerned:

- High Occurrence, High Total Link Strength: Keywords situated in the upper-right quadrant of the plot, such as "smart power grids", "electric power transmission networks," and "smart grid," exhibit both high occurrence and high total link strength. For instance, "smart power grids" has an occurrence of 3572 and a total link strength of 24,102, indicating that it is not only frequently mentioned but also strongly linked across various sources. These keywords likely represent core concepts and focal points within the domain of Smart Energy Systems, attracting substantial attention and interest from researchers and practitioners alike.
- Low Occurrence, High Total Link Strength: Keywords positioned in the lower-right quadrant of the plot possess relatively low occurrence but high total link strength. Despite being less frequently mentioned, these keywords hold significant importance within specific niches or specialized areas of Smart Energy Systems. For instance, terms like "particle swarm optimization (PSO)" and "distributed power generation" may have limited occurrences in the dataset but are extensively linked, suggesting their relevance in specialized contexts or research domains.
- High Occurrence, Low Total Link Strength: Keywords falling in the upper-left quadrant exhibit high occurrence but low total link strength. These keywords are frequently mentioned but lack strong linkages across sources. For example, generic terms like "energy" or "power" are commonly referenced but may not be deeply interconnected or elaborately discussed in the dataset. Despite their frequent occurrence, these keywords

may represent broad concepts or overarching themes without specific associations or detailed discussions.

- Low Occurrence, Low Total Link Strength: Keywords located in the lower-left quadrant have both low occurrence and low total link strength. These keywords are infrequently mentioned and have limited linkages, indicating their marginal significance within the dataset. Terms like "air conditioning" and "heat storage" may fall into this category, representing relatively specialized topics that are not extensively discussed or linked within the context of Smart Energy Systems.

In focused researches, the most frequently occurring keyword is "smart grid". This keyword is appearing 1308 times with a total link strength of 1905, indicating its central role in this domain. Following closely are terms like "renewable energy" (645 occurrences, total link strength 913), "demand response" (520 occurrences, total link strength 888), "energy management" (422 occurrences, total link strength 724), and "microgrid" (442 occurrences, total link strength 684) (Table 2). In Figure 5 the data plot reveals distinct patterns based on the relationship between total link strength and occurrence for author keywords:

- High Occurrence, High Link Strength. This region of the plot contains keywords with both high occurrences and high total link strengths. Example keywords include "smart grid" (1308 occurrences, total link strength 1905), "renewable energy" (645 occurrences, total link strength 913), "demand response" (520 occurrences, total link strength 888), "energy management" (422 occurrences, total link strength 724), and "microgrid" (442 occurrences, total link strength 684).
- High Occurrence, Low Link Strength. Keywords in this area have high occurrences but relatively low total link strengths. Examples include "machine learning" (369 occurrences, total link strength 575), "electric vehicles" (332 occurrences, total link strength 481), "energy storage" (294 occurrences, total link strength 463), and "internet of things (IoT)" (302 occurrences, total link strength 419).
- Low Occurrence, High Link Strength. Keywords here have low occurrences but high total link strengths, indicating strong connections despite being mentioned less frequently. Examples include "blockchain" (282 occurrences, total link strength 440), "artificial intelligence" (181 occurrences, total link strength 341), and "deep learning" (227 occurrences, total link strength 327).

In the table 2 are selected keywords for it.

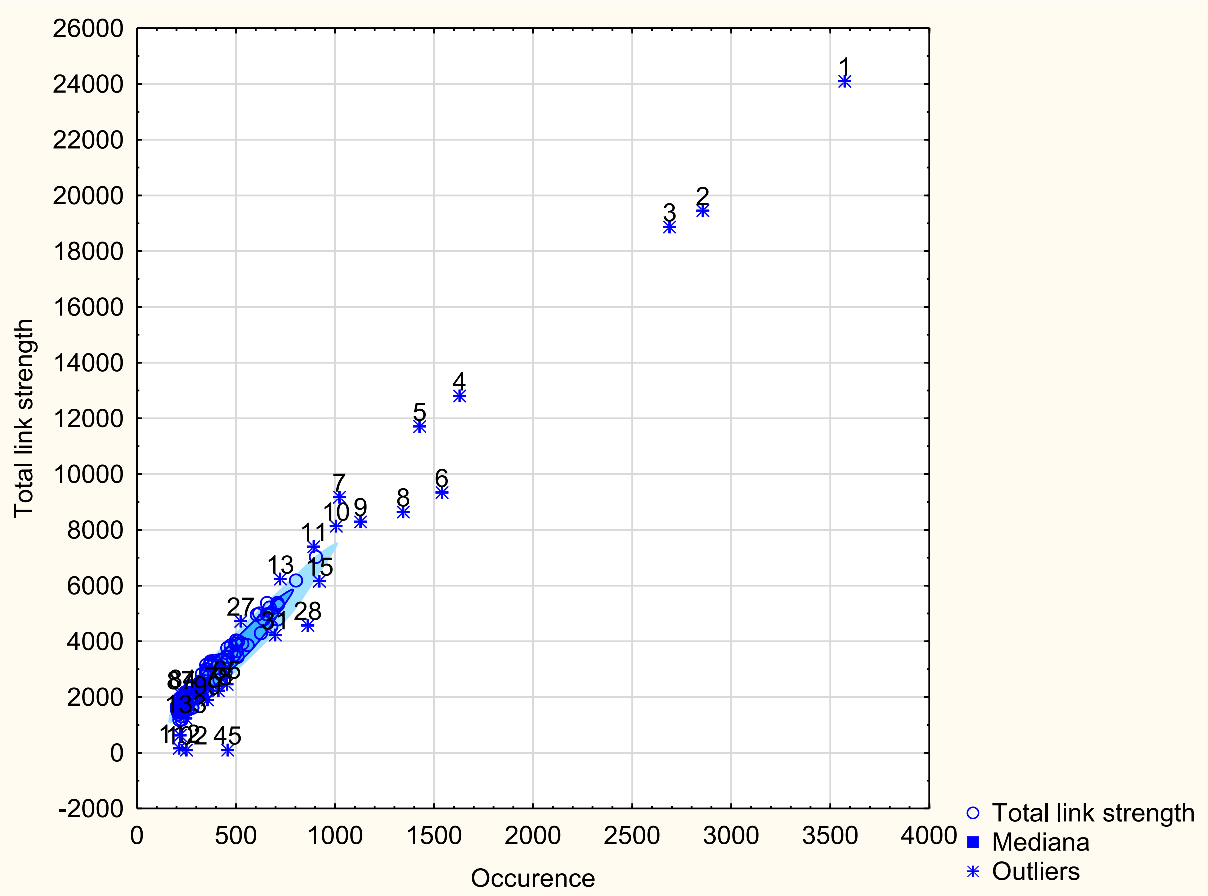

Figure 5. Bag plot – total link strength vs occurrence for author keywords.

Source: results of analysis by using computer programme (Statistica).

Table 2.
The of papers about Smart Energy System from Scopus according to keywords – selected keywords

Number	Key words	Occurrence	Total link strength
1	smart grid	1308	1905
2	renewable energy	645	913
3	demand response	520	888
4	energy management	422	724
5	microgrids	442	684
6	smart grids	425	581
7	machine learning	369	575
8	optimization	292	539
9	electric vehicles	332	481
10	energy storage	294	463

Empirical results indicate that "smart grid", "smart power grids", and "electric power transmission networks" are among the most popular topics in world research on Smart Energy Systems (SES) for 2020-2024. The outcome depends on the theoretical basis advanced by Lund et al. (2012, 2017), who emphasized the transition from a grid-constrained electricity paradigm to an integrated smart energy system approach. They propose that SES would have to put some areas—electricity, heat, transport—under one roof through smart infrastructure and information technology to achieve systemic optimisation. Bibri et al. (2017) also agreed on such an integrated concept by referring to coordination across sectors, digital management systems, and green city planning while formulating next-generation smart cities and energy systems.

The most evident conclusion of statistical findings is the frequency and intensity of co-occurrence of terms like "energy efficiency", "energy management", and "renewable energy resources". The trends reinforce earlier research findings of Dincer and Acar (2017), who highlighted the top priority for smart energy systems to meet sustainability objectives should be efficient use of energy and renewables integration. This corresponds to Xu et al. (2020) emphasis on SES system design with intelligent control, automation, and performance optimization. Furthermore, ubiquitous presence of "microgrids" as a new development mirrors the outcome of Mbungu et al. (2020), who asserted that decentralized smart-controlled microgrid systems offer tremendous potential to improve reliability, resilience, and cost-effectiveness in small-scale energy systems.

Categorization of emergent technologies as "blockchain", "IoT", "machine learning", and "artificial intelligence" outlier but increasingly forceful terms defines the trend towards digitalized, autonomous, and decentralized SES designs. The same has been attested by Erturk (2019), who studied the use of blockchain for safe peer-to-peer trading and energy data exchange, and Khatua et al. (2019), who quoted IoT and AI as enablers of system-wide responsiveness and automation. Simultaneously the demand for advanced optimization techniques in system and control design, as referenced by Fadaee and Radzi (2012) and Suganthi et al. (2015), is in the same ratio the primary frequency of "optimization" as the search term in the literature. Overall, the findings indicate a shift in paradigm in SES research towards the integration of Fourth Industrial Revolution uses of technology for adaptive and real-time energy management in various applications and scales.

5. Conclusion

From 2020 to 2024, global research activity in Smart Energy Systems (SES) has been marked by staccato convergence of green needs and technology advancement, as evidenced in the dominant science trends and theme concentrations in the bibliometric overview. The most frequently used terms, i.e., “smart grid”, "smart power grids", "electric power transmission", "renewable energy resources", "energy management", and "energy efficiency", suggest caution with system optimization, integration of renewable energy, and digital control technology advancement (RQ1 and RQ2). In a broader sense, the augmented usage of the terms "Internet of Things (IoT)", "optimization", and "blockchain" is reflective of the augmented utilization of data-driven, networked infrastructure in advancing energy system responsiveness, flexibility, and sustainability. Thematic co-occurrence clustering and keyword network visualization indicate a multidisciplinary technology space with clusters in smart grid technology, renewable integration, digital management systems, and automation. This aligns with the growing maturity of the field and its overlap with global goals of decarbonization, decentralized power generation, and smart system integration, and places SES research at the nexus of management, environmental policy, and information science.

The emergent topics in SES literature and outlying words during 2020-2024 represent a strategic agenda of digitalization, decentralization, and cross-sectoral integration of energy systems. “IoT”, "Blockchain", "machine learning", "deep learning", "artificial intelligence" are the most emergent new topics in the SES research could focus on intelligent automation, decentralized transactional systems, and other energy carriers capable of enhancing system resilience and sustainability.

Limitation of our analysis: One of the principal disadvantages of this research is the use of the Scopus database exclusively, although broad, and hence potentially excluding relevant publications in other indexing databases that could reduce bibliometric analysis coverage. Furthermore, keyword-based mapping and co-occurrence network focus might ignore more sophisticated conceptual development deserving detailed qualitative examination beyond frequency statistics' capabilities.

The subsequent analyses are suggested to be carried out through multi-databases, i.e., Web of Science and IEEE Xplore, in order to make bibliometric evaluation encompass a wide range of scholarly output. In addition, combining bibliometric analysis with qualitative content analysis or case studies would likely yield even richer contextual intelligence regarding driver forces and policy pressures to guide Smart Energy System design.

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