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Bibliometric Study of the Intersection Between Green Energy and Artificial Intelligence: Business- and Economy-Related Studies

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ABSTRACT

The rapid convergence of artificial intelligence (AI) and green energy (GE) is transforming sustainable business practices, energy management, and economic development. Although research in this interdisciplinary field has expanded considerably, its intellectual structure, thematic evolution, and business implications remain insufficiently understood. This study presents a comprehensive bibliometric analysis of AI and GE research from a business and economics perspective. Publications were retrieved from the Scopus and Web of Science databases using an expanded, transparent, and reproducible search strategy. Following PRISMA guidelines and predefined inclusion criteria, a final dataset of 7,301 publications was analyzed using Bibliometrix and VOSviewer to examine publication trends, influential authors, institutions, countries, journals, collaboration networks, and thematic structures. The results reveal a marked increase in scientific production after 2022, reflecting the growing integration of AI into renewable energy systems and sustainable development research. Scientific output is concentrated in countries with strong research capacity, sustained investment in digital innovation, and ambitious sustainability agendas. Keyword co-occurrence analysis identifies four dominant research themes: sustainability and energy policy, AI-driven forecasting and optimization, smart energy systems, and digital transformation for energy efficiency. The findings demonstrate that the field has evolved from predominantly technical applications toward a multidisciplinary research domain integrating business strategy, innovation management, sustainability, and energy economics. Unlike previous bibliometric studies based on narrower search strategies or smaller datasets, this study provides a transparent, large-scale mapping of the field and offers a more comprehensive understanding of its intellectual structure and emerging research directions. The findings provide valuable insights for researchers, policymakers, managers, and investors seeking to accelerate sustainable energy transitions and support long-term economic resilience.

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1. Introduction

The global challenge and the ever-worsening effects of climate change and biodiversity loss have put green energy (GE) and its sources into focus in both developed and developing countries [1]. Artificial intelligence (AI) and GE are increasingly recognized as complementary drivers of sustainable economic development. While renewable energy technologies contribute to decarbonization and energy security, AI provides advanced analytical and decision-support capabilities that improve forecasting, optimize resource allocation, enhance grid stability, and increase the operational efficiency of renewable energy systems. From a business and economics perspective, AI also facilitates investment planning, energy market optimization, predictive maintenance, and strategic decision-making, thereby supporting the transition toward more competitive, resilient, and sustainable energy markets. Consequently, understanding how these two fields converge has become an important research priority for academics, policymakers, and industry practitioners.

Despite the rapidly growing body of scholarly literature on AI and GE, studies examining their intersection from a business and economics perspective remain limited. Existing work has mostly focused on technological and engineering applications, and little to no attention has been given to understanding the intellectual structure, research trends, and thematic evolution of this interdisciplinary field. Consequently, a more comprehensive bibliometric assessment is needed to identify the current state of research, influential contributors, emerging themes, and future research directions. The novelty of this study lies in providing a comprehensive bibliometric analysis of research at the intersection of AI and GE by combining data from the Scopus and Web of Science databases and focusing specifically on business, management, and economics-related publications. Using a transparent PRISMA-based methodology and advanced bibliometric techniques, including keyword co-occurrence analysis, thematic mapping, and collaboration network analysis, this study offers a systematic overview of the field and identifies its major research streams and emerging trends.

Therefore, the main objective of this systematic literature research is to identify and analyze the relevant published studies in the Scopus and Web of Science databases regarding the intersection between the two research areas (GE and AI) in business and economy-related studies. Moreover, another purpose of this paper is to raise awareness among scholars, researchers, analysts and policymakers regarding the potential use of AI technologies in GE development globally.

The findings contribute to the existing literature by providing a reproducible overview of the evolution of research in this domain while highlighting opportunities for future interdisciplinary research. In addition, the results offer valuable insights for researchers, policymakers, and business practitioners seeking to understand how AI technologies can support the transition toward more sustainable and intelligent energy systems.

The following sections make up the remainder of the study: The detailed description and theoretical background on both the AI and GE are highlighted in Section 2. Section 3 reveals the research methodology and research framework. Section 4 presents the results of the study and Section 5 opens up a thorough discussion regarding the main and most interesting findings and concludes the paper, pointing to important scientific and practical implications and outlining potential future study directions in this field.

2. Theoretical Foundations

2.1 Historical development and theoretical foundations of AI

AI has evolved significantly since its inception in 1956 and has progressed through “several cycles of fast progress and periods of apparent stagnation” [2]. The field's foundations lie in mathematics, engineering, psychology, and philosophy [3]. Early challenges included limited computer storage and

high costs. Today, AI encompasses various technologies, including natural language processing, machine learning, and robotics [4].

Industry 4.0 can be considered “a reality, a paradigm integrating modern technologies and innovations, and the leading component of the industrial transformation enabling intelligent machines to execute tasks autonomously such as self-monitoring, interpretation, diagnosis, and analysis” [5]. AI “inspires new approaches, contributes to the energy transition as an important technological building block and - often unnoticed - is already part of numerous applications and business environments” [6].

AI is defined as “a system’s ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation” [7].

Furthermore, AI encompasses various subfields, including machine learning, deep learning, and data analytics [8]. It is rapidly evolving, with significant potential to impact various industries including healthcare, finance, transportation, manufacturing, retail, supply chain, logistics and utilities, “all potentially disrupted by the onset of AI technologies” [9].

2.2 Theoretical foundations of GE

The ever-increasing and one of the most urgent global environmental issues of climate change is intrinsically linked to the current and future need for energy. Renewable and GE has emerged as a future solution, and many renewable energy technologies have been developed for different purposes [10].

Green (also known as clean) energy is a form of energy that “can be used regularly and cannot be depleted” and encompasses solar, wind, hydro, tidal and geothermal energies. GE is considered “a sustainable solution to the socioeconomic concerns associated with environmental issues and the depletion of non-renewable sources of energy” [11]. The term “green” stems from the reduction of energy consumption through energy efficiency [12] and “refers to power generated in a way that does not impact the surrounding ecosystem” [13]. In other words, GE derives from natural resources [14].

GE is “frequently associated with sustainable development”, and seeks to reduce global warming and its adverse effects on the environment, economy, and social justice [15]. GE “is taking on an increasingly important role” [16] and is the key to sustainable development and environmental protection. It is considered to be an alternative to fossil fuels, which have contributed to climate change, pollution, and ecosystem degradation, and its adoption is not only environmentally beneficial but also economically advantageous, potentially reducing electricity costs and promoting energy security [17, 18].

GE positively impacts greenhouse gas emissions, the diversification of the energy supply and the dependence on volatile and uncertain fossil fuel markets [16]. GE investment and renewable energy consumption decrease carbon emissions in the long run, unlike non-renewable energy consumption and economic growth, which increase carbon emissions in shorter and longer periods [12].

There is a bright future for GE sources, especially considering governments globally are undertaking viable solutions to the energy crisis and increasing awareness of the large dependence on fossil fuels. Moreover, there is a growing interest in and support for GE sources [16]; however, effective energy management systems are crucial for maximizing the benefits of GE, as energy saving is as important as energy production [17]. Most importantly, GE is considered and recognized as the best strategy for sustainable development [12]. Lately, GE sources and production are considered the “basis for efficient operation of the world’s economies” and therefore, the energy sector is a vital political, economic and social aspect of every economy [19]. Notwithstanding, sources of GE are available in all countries, but their full potential has not yet been realized [14].

3. Research Methods

This study adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [20] as shown in Figure 1. The study follows a methodological process based on PRISMA in 4 stages, i.e. the identification stage, the screening stage, the eligibility stage, and the inclusion stage. Data for this study were obtained on July 20th 2026, from both the Scopus and Web of Science databases without imposing any limitations on the publication year.

The PRISMA offers “a coherent methodology to adequately guide the search for documents” [21]. The PRISMA guidelines were first published in 2009, as a way to improve the reporting quality of systematic reviews and meta-analyses [22]. These guidelines have been widely adopted and cited in the healthcare literature [21]. In 2015, PRISMA-P was introduced to specifically address the reporting of review protocols, emphasizing the importance of planning and documenting review methods to reduce bias and duplication [23]. The PRISMA statement was updated in 2020 to reflect advancements in systematic review methodology and terminology over the past decade. These guidelines continue to benefit authors, editors, reviewers, and healthcare providers by enhancing the transparency and quality of systematic review reporting [21].

This study combines a systematic literature search based on the PRISMA framework with bibliometric analysis. PRISMA was employed exclusively to ensure a transparent and reproducible identification and screening process, whereas Bibliometrix and VOSviewer were used to perform the bibliometric analyses and to identify and visualize emerging trends and topics in GE and AI research. These research subjects are novel, and the period captured with the surveyed papers encapsulates “significant global disruptions, such as the COVID-19 pandemic and geopolitical tensions”, which have influenced research trends in GE and AI [24].

The database's search criteria are shown in Figure 1. Specifically, only the two globally renowned scientific databases, Scopus and Web of Science, were considered, and all other databases were excluded from the analysis. A comprehensive search strategy incorporating multiple synonyms related to GE and AI was employed. The search was further restricted to publications indexed in relevant subject areas, including Business, Management and Accounting, Economics, Social Sciences, and Decision Sciences, as well as English-language publications and eligible document types (articles, reviews, conference papers, and book chapters).

Although the survey included the Scopus subject areas Business, Management and Accounting, Economics, Econometrics and Finance, Decision Sciences, and Social Sciences, the latter two categories were not considered independently. They were included because research on AI and GE is inherently interdisciplinary and many studies addressing business decision-making, technology management, innovation, sustainability policy, and strategic planning are indexed within these categories. During the screening stage, publications were retained only if their primary focus addressed business, management, economic, organizational, policy, or decision-making aspects of AI in GE. Studies focused exclusively on engineering, electrical design, mathematical optimization, or technical algorithm development without managerial or economic relevance were excluded.

3.1 Research questions

Guided by the dearth of literature, the following research questions are tackled in this study, as shown in Table 1.

Table 1

Research questions of this study and their application

No	Research question	Application
RQ1	How has research on AI in GE evolved within the business and economics literature?	To explain the evolution of the field, identify major publication trends, and interpret the technological, economic, and policy factors driving its rapid growth.
RQ2	Which authors, institutions, journals and countries have shaped the intellectual development of this research field?	To identify the leading scientific contributors and evaluate how collaboration, institutional capacity, and national innovation ecosystems have influenced the development of the field.
RQ3	What conceptual themes and emerging research directions characterize the intersection between AI and GE?	To map the intellectual structure of the field, identify dominant and emerging research themes, reveal existing research gaps, and propose future directions for interdisciplinary research from a business and economics perspective.

Source: Prepared by authors, inspired by [1].

3.2 Search strategy

A search method was employed that incorporated terms associated with GE, AI and their intersection (Figure 1). The search strategy was implemented using the database-specific search fields available in Scopus and Web of Science. In Scopus, the search query was applied to the "TITLE-ABS-KEY" field, which searches titles, abstracts, and keywords, whereas in Web of Science, the corresponding search was conducted using the "All Fields" option. These fields are database-specific and are not assumed to be methodologically equivalent; differences in database coverage, indexing practices, and search functionality may therefore lead to differences in the records retrieved from the two databases.

The search query used is as follows:

("green energy" OR "renewable energy" OR "clean energy" OR "sustainable energy" OR "renewable power" OR "green power" OR "renewable electricity" OR "energy transition" OR "low-carbon energy" OR "carbon-neutral energy" OR decarbon*) AND ("artificial intelligence" OR AI OR "machine learning" OR "deep learning" OR "neural network*" OR "expert system*" OR "intelligent system*" OR "computational intelligence" OR "data mining" OR "predictive analytics" OR "reinforcement learning" OR "natural language processing").

The initial search identified 50,284 records, comprising 6,689 publications from Scopus and 43,595 publications from the Web of Science. After applying the predefined language, subject-area, and document-type filters within the databases, 7,700 records met the eligibility criteria and were exported for further analysis. Subsequently, 39 duplicate records were identified and removed, leaving 7,661 unique publications for title and abstract screening.

Screening was conducted independently according to predefined inclusion and exclusion criteria. During the screening phase, publications that did not primarily address the intersection of AI and GE, fell outside the scope of business and economics, or did not satisfy the predefined inclusion criteria were excluded. Moreover, publications were excluded if they: (i) focused exclusively on engineering, electrical, or computer science applications without a clear business, management, economics, policy, or decision-making perspective; (ii) addressed AI without a direct application to green or renewable energy; (iii) investigated green or renewable energy without incorporating AI or related intelligent technologies; (iv) consisted of editorials, notes, letters, book reviews, or other non-research documents that did not meet the selected publication types; or (v) were identified as duplicate records across the two databases. The remaining publications were manually assessed to ensure their relevance to the business and economics focus of this study. In cases where the database

subject classification alone was insufficient, the title, abstract, and, where necessary, the full text was examined to confirm that the study addressed managerial, organizational, economic, strategic, policy, or decision-making aspects of AI in the context of GE.

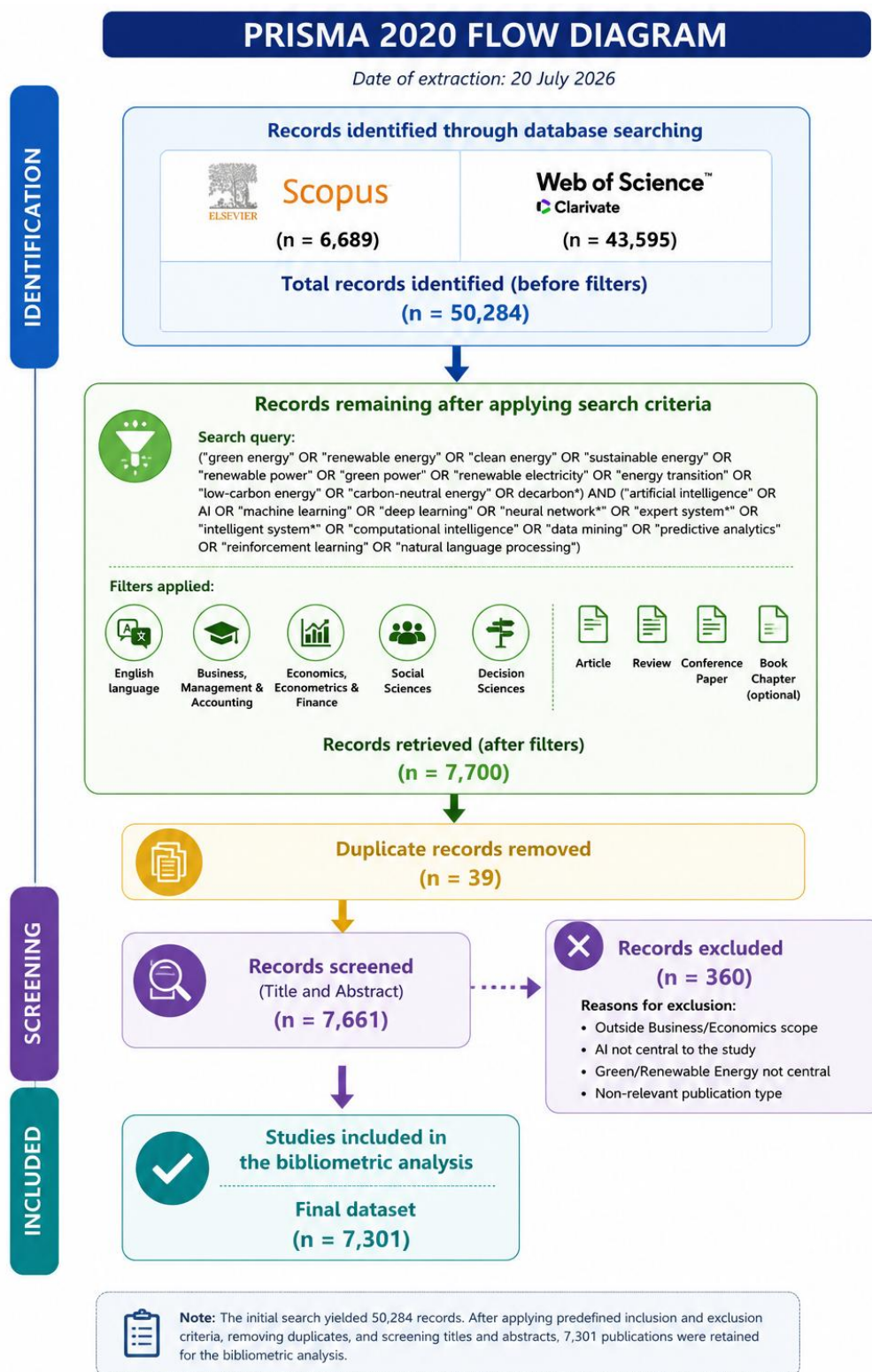


Fig. 1. Search and selection criteria used according to the PRISMA guidelines

Following this systematic screening process, 7,301 publications were retained and included in the final bibliometric analysis. These records formed the basis for all subsequent analyses, including publication trends, citation analysis, collaboration networks, keyword co-occurrence analysis, and thematic mapping.

The complete study selection process is illustrated in Figure 1, providing a transparent overview of the identification, screening, eligibility, and inclusion stages undertaken to construct the final bibliometric dataset. This structured procedure enhances the reproducibility of the study and ensures that the analyzed literature accurately represents contemporary research at the intersection of AI and GE from a business and economics perspective.

3.3. Software analytical tools: Bibliometrix (Biblioshiny) and VOS Viewer

The analyses and graphical visualisations in this study were conducted with the application of Bibliometrix, an advanced open-source R package, which is “recognized for its methodological rigor, reproducibility, and analytical depth” [25, 26]. Specifically, the Bibliometrix package and its web interface, biblioshiny, were used to perform data pre-processing, descriptive analyses, and science mapping.

VOSviewer (version 1.6.20) is a computer program developed for visualizing bibliometric maps, with “a special attention to the graphical representation of bibliometric maps” [27]. It was selected because of its recognized capability to generate high-quality static network visualizations [25].

4. Results

An overview of the main information/data regarding the current bibliometric study is revealed in Figure 2. The results from the bibliometric study reveal that 7,301 papers in the intersection of GE and AI were relevant and analysed in this study. These 7,301 manuscripts were published in 2,365 journals (venues for publication) by a total of 18,608 authors. There were 524 single-authored papers, and the average number of co-authors per paper is 3.93. International co-authorship is 5.684%, and the annual growth rate is 36.73%. Although the field exhibits a remarkable annual growth rate of 36.73%, indicating increasing scientific and strategic interest, the low international co-authorship rate of only 5.684% suggests that collaboration across different countries remains relatively limited. Strengthening international research partnerships could facilitate knowledge transfer, foster interdisciplinary innovation, and accelerate the development of AI-driven solutions for global sustainable energy challenges.

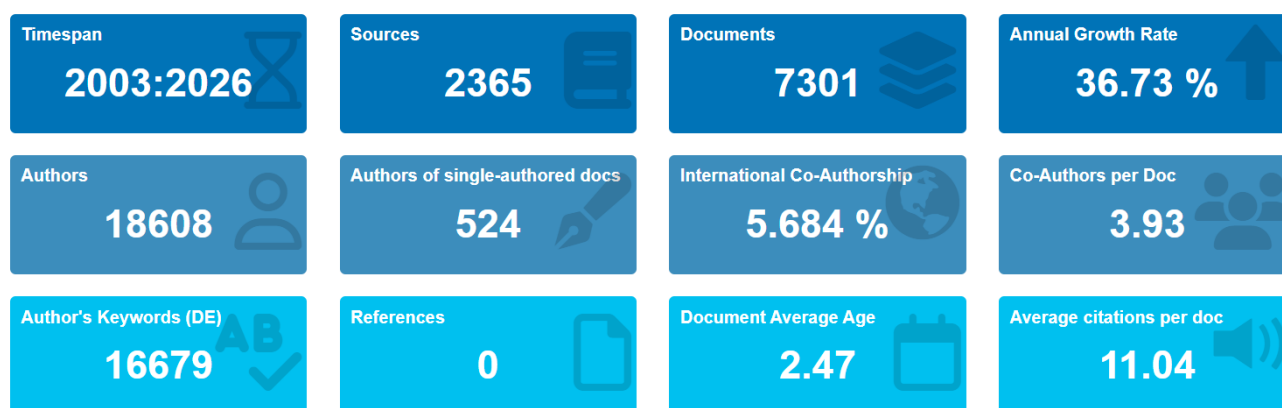


Fig. 2. Main information regarding the bibliometric study

4.1 Evolution of research on AI and GE (RQ1)

The results show a boom in the intersection between GE and AI, especially in the period from 2022 onwards, as shown in Figure 3. Considering that this is a relatively novel subject, these results were expected, and the sharp increase in scientific production after 2022 reflects the convergence of several technological, economic, and policy developments. The observed acceleration suggests that research activity is responding not only to technological advances in AI but also to broader economic and policy developments promoting digital transformation and decarbonization. Consequently, the expansion of the literature reflects the increasing strategic importance of AI for improving energy efficiency, supporting sustainable business models, and facilitating evidence-based decision-making in the energy sector. First, rapid advances in AI, particularly in machine learning, deep learning, and generative AI, have significantly expanded opportunities for optimizing renewable energy systems, improving forecasting accuracy, and supporting intelligent energy management. Second, growing international commitments to carbon neutrality and sustainable development, reinforced by initiatives such as the European Green Deal, the Paris Agreement, and national net-zero strategies, have inspired further research and investment in renewable energy technologies. Finally, increasing public and private investments in digital transformation and green innovation have encouraged interdisciplinary research linking AI with energy efficiency, smart grids, and sustainable business models. Consequently, the observed growth may represent not only rising academic interest but also the increasing strategic importance of AI in supporting the global transition toward a low-carbon economy.

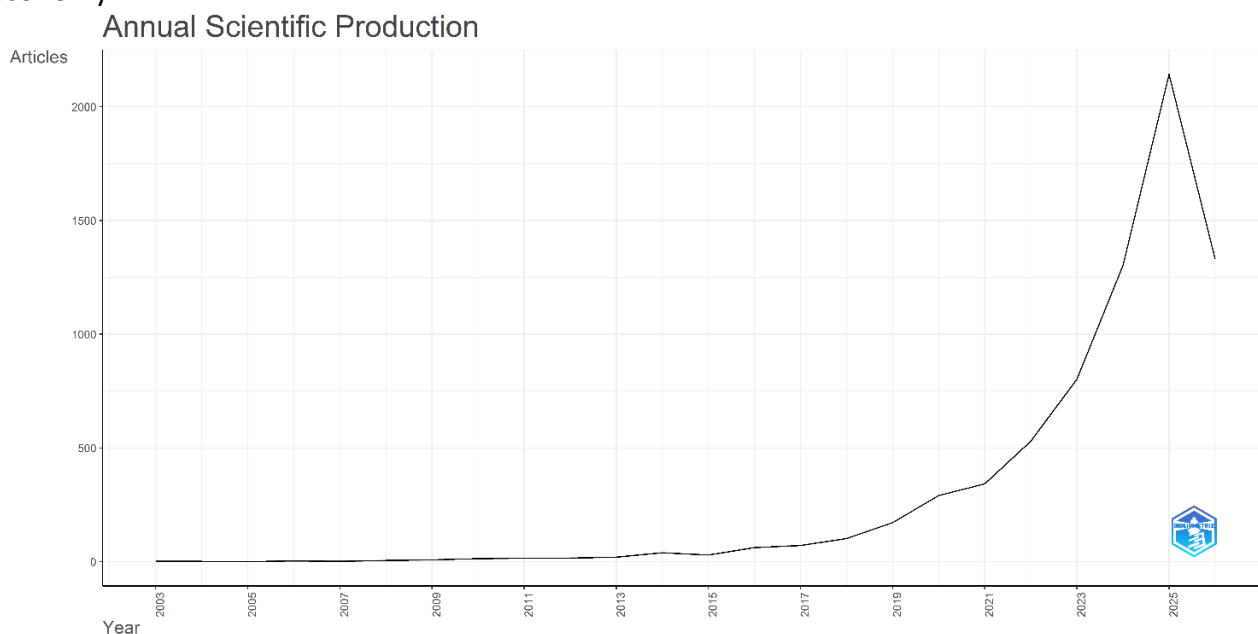


Fig. 3. Annual trends in publications in GE and AI

Note: The publication count for 2026 represents records available in Scopus and Web of Science up to 20 July 2026, the date of data collection, and therefore does not represent the complete annual output for 2026.

From a business and economics perspective, this trend highlights the growing recognition of AI as a strategic capability that enables organizations to improve operational efficiency, optimize resource allocation, reduce environmental impacts, and enhance competitiveness within rapidly evolving energy markets.

4.2 Scientific performance and intellectual structure (RQ2)

When addressing the second research question, it is vital to present the most relevant sources (journals), the most impactful sources (citations/H-index), the most productive authors, the most relevant affiliations, the most cited countries and the top cited documents in this research field.

Figure 4 reveals and lists the most prolific journals in the research area. Sustainability Journal leads with 490 publications, and is followed by Journal of Cleaner Production and Expert Systems with Applications (with 248 publications each). However, Figure 5 presents the most impactful sources (measured by citations and H-index). Even though the Sustainability Journal is the most relevant source as presented in Figure 4 (i. e. the journal with the most published work in this research area), the Journal of Cleaner Production has been the most prominent and first choice for top-cited articles in this research area. As shown below in Table 3, four out of the top ten most cited and most relevant articles in this research area were published in the Journal of Cleaner Production.

The predominance of energy- and sustainability-oriented journals demonstrates that research on AI in GE has moved beyond purely engineering applications and increasingly addresses issues related to business performance, sustainable business strategies, policy design, and environmental management. This finding confirms the interdisciplinary nature of the field and its growing relevance within business and economics research.

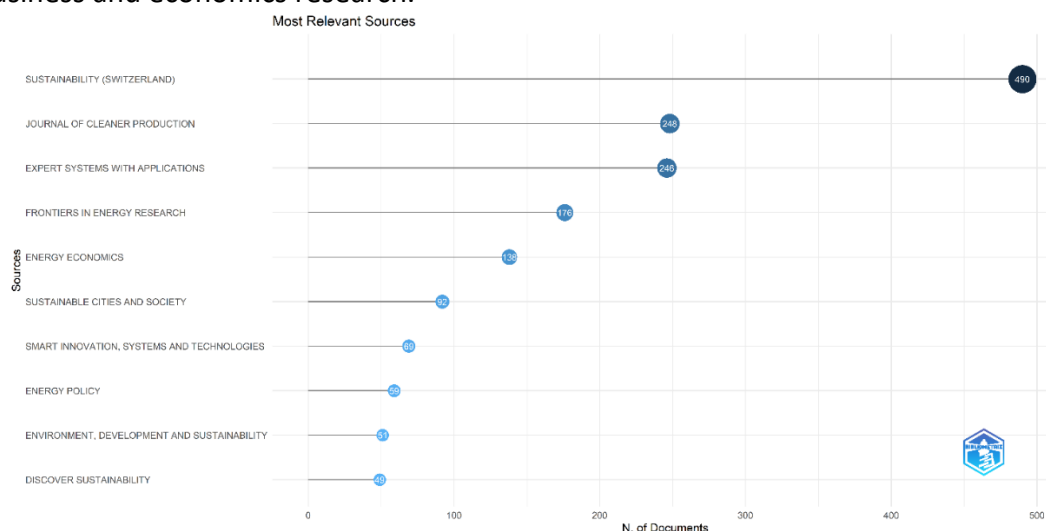


Fig. 4. The most relevant sources

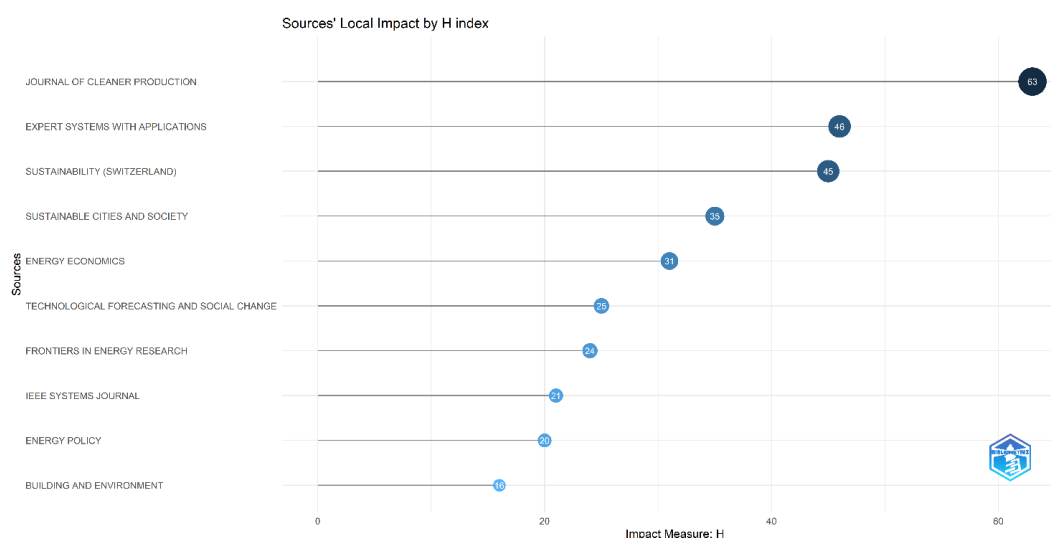


Fig. 5. The most impactful sources (by H-index)

In Table 2, the most productive authors are presented. The author Wang Y. is the one with the most published papers (a total of 90 papers), followed by Li Y., Zhang Y., Wang J., Li J with 80, 75, 69 and 68 papers, respectively. This concentration of publications among a relatively small group of researchers indicates the emergence of a stable scientific community that is actively shaping the intellectual development of the field. Their work has established methodological foundations and stimulated collaboration across disciplines, contributing to the rapid expansion of AI applications in renewable energy research.

Table 2

Most productive authors in the intersection between GE and AI

Author (full name)	Documents	Affiliation	Scopus Author ID / ResearcherID
Ahmed Ali	15	Department of Business Administration, Plasma University, Mogadishu, Somalia	Scopus Author ID 55452417200
Bhupinder Singh	15	Sharda University, Uttar Pradesh, Greater Noida, India	Scopus Author ID 58806881100
Rongrong Li	13	School of Economics and Management, China University of Petroleum (East China), Qingdao, China	Scopus Author ID 56896517000
Qiang Wang	13	Laboratory for Asian Economic Studies, Saint Petersburg State University, Saint Petersburg, Russian Federation	Scopus Author ID 56953841500
Vangelis Marinakis	13	National Technical University of Athens, Decision Support Systems Laboratory, Athens, Greece	Scopus Author ID 55386639700
Polamarasetty P. Kumar	12	GMR Institute of Technology, Department of Electrical and Electronics Engineering, Rajam, India	Scopus Author ID 57219197736
Ramakrishna S. S. Nuvvula	12	NMAM Institute of Technology, Nitte (Deemed to Be University), Department of Electrical and Electronics Engineering, Karnataka, India	Scopus Author ID 57205725706
Ahmed Imran Hunjra	12	Chair Towards Inclusive Co., IPAG Business School, Paris, France	ResearcherID G-7795-2017
Tomonobu Senjyu	11	University of the Ryukyus, Nishihara, Japan	Scopus Author ID 57535907000
Raghu Raman	10	Amrita School of Business, Amrita Vishwa Vidyapeetham, Kerala, India	Scopus Author ID 36618183700

Table 3 presents the 10 most cited articles in the field of GE and AI. The most cited articles in the field are Ahmad *et al.*, [28], with 1,104 citations, followed by Ahmad *et al.*, [29], and Ren *et al.*, [30], with 580 and 559 citations, respectively. This insight reveals more than the results in Table 3 (the most productive authors), since it reveals whose work is most influential and contributes to the scholarly field. Highly cited publications primarily focus on methodological advances in AI and their

application to sustainable energy systems. Their influence suggests that foundational AI methodologies continue to provide the conceptual basis for subsequent studies addressing renewable energy optimization, forecasting, energy efficiency, and sustainability.

Table 3

Top cited articles in the field of GE and AI

Authors	Year	Source title	Cited by
Ahmad <i>et al.</i> , [28]	2021	Journal of Cleaner Production	1104
Ahmad <i>et al.</i> , [29]	2018	Journal of Cleaner Production	580
Ren <i>et al.</i> , [30]	2014	Knowledge-based systems	559
Petropoulos <i>et al.</i> , [31]	2022	International Journal of Forecasting	548
Ahmad <i>et al.</i> , [32]	2020	Sustainable Cities and Society	472
Li <i>et al.</i> , [33]	2020	Journal of Cleaner Production	464
Kumari and Toshniwal [34]	2021	Journal of Cleaner Production	400
Mardani <i>et al.</i> , [35]	2016	Sustainability	391
Xu <i>et al.</i> , [36]	2019	Resources Policy	389
Bryant and Lempert [37]	2010	Technological Forecasting and Social Change	369

In Figure 6, the most relevant affiliations are revealed. Namely, Tsinghua University (China) has the most (56) publications in the intersection between GE and AI and is followed by the University of Johannesburg (South Africa) with 54 citations and the Southeast University (Bangladesh) with 50 citations. The leading affiliations are primarily universities and research institutions with strong capacities in engineering, energy systems, and digital technologies. Their prominence reflects the importance of interdisciplinary research environments where expertise in AI, renewable energy, economics, and sustainability can be integrated. This also highlights the role of institutional investment and international collaboration in advancing innovation within the field.

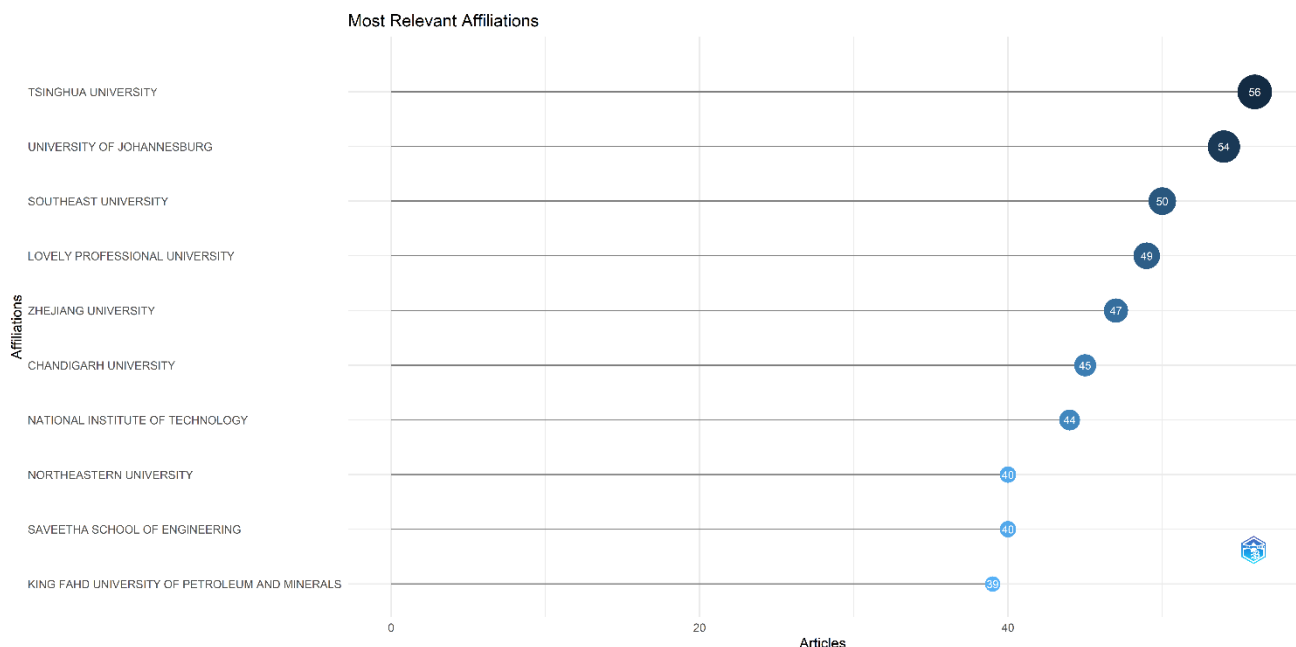


Fig. 6. Most relevant affiliations

The most cited countries (Figure 7) are China, which leads by a considerable margin with 20,614 citations, followed by India and the USA, with 5,415 and 4,749 citations, respectively. China's leading position may be associated with its substantial research activity in renewable energy and AI, together

with strong institutional and policy support for innovation and technological development. The country's focus on carbon neutrality and the deployment of smart energy technologies may also provide a favorable context and environment for research in this interdisciplinary field. Similar patterns can be observed in other highly productive countries, where established research capacity, institutional support, and international collaboration may contribute to higher levels of scientific output and impact. These factors should be understood as contextual explanations rather than as direct causal relationships established by the present bibliometric analysis.

Collectively, these findings indicate that scientific leadership is concentrated within countries and institutions characterized by strong research capacity, substantial investments in renewable energy technologies, and national strategies supporting AI and sustainable development. More importantly, it is vital to acknowledge that citation performance indicates not only scientific productivity but also international visibility and influence. Countries with high citation impact frequently serve as knowledge hubs, producing research that shapes subsequent developments across both technological and business-oriented studies.

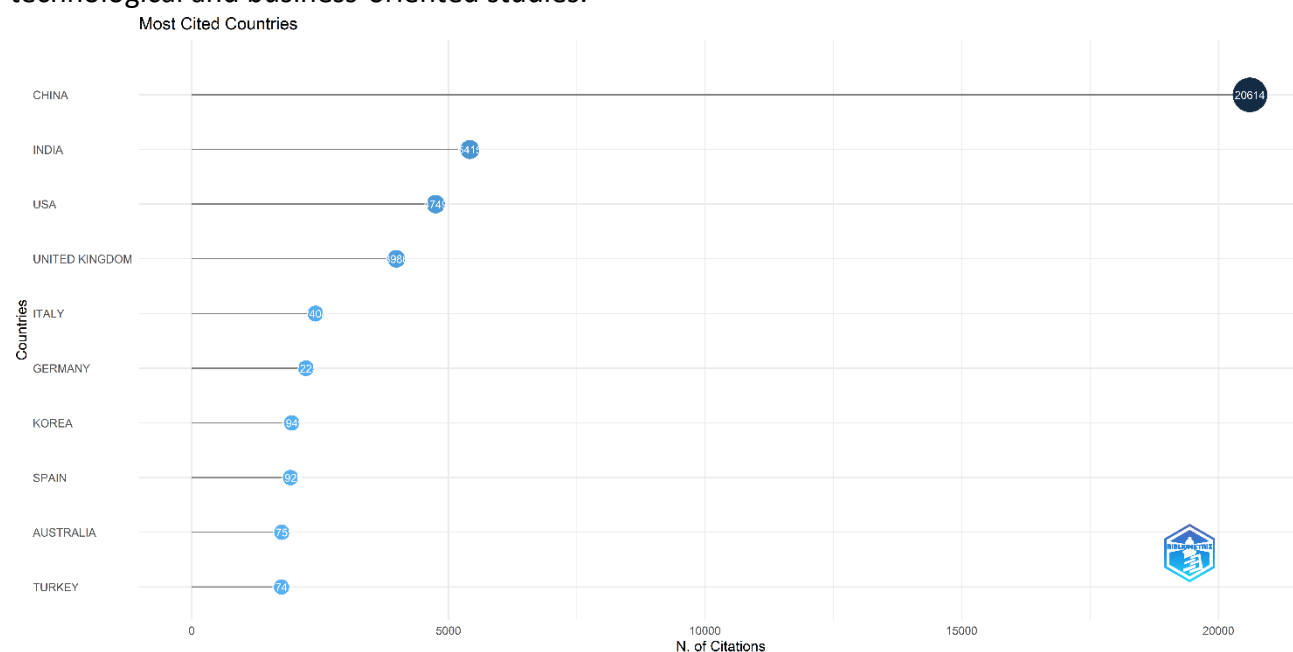


Fig. 7. Most cited countries

4.3 Conceptual structure and emerging themes (RQ3)

Regarding the topics and trends in the intersection between GE and AI, Figure 8 reveals the most used keywords in the surveyed papers in a word cloud form. Word clouds are visual representations of text that display words proportionally sized based on their frequency or importance [38, 39].

The co-occurrence network visualization in Figure 9 was generated using VOSviewer and represents the keyword co-occurrence network of publications on AI and GE. The size of each node mirrors the frequency with which a keyword appears in the dataset, while the thickness of the connecting lines reveals the strength of co-occurrence between keywords. The distance between nodes reflects the degree of relatedness, with closely positioned keywords frequently appearing together in the same publications. Different colours denote clusters of keywords that represent distinct but interconnected research themes within the field. In this study, there are four clusters as follows.



Fig. 8. Word cloud of the keywords

The red cluster represents the business, sustainability, and policy dimension of the scholarly literature. It is centered around the keywords “artificial intelligence”, “sustainable development”, “sustainability”, “energy policy”, and “alternative energy”. The terms “green economy”, “innovation”, “carbon dioxide”, “emission control”, “economic growth”, and “environmental technology” reveal that this research stream focuses on the strategic and economic implications of AI-enabled GE systems. These studies primarily focus on how AI contributes to sustainable development, environmental governance, carbon reduction strategies, and energy policy formulation. The prominence of this cluster demonstrates the growing interest in integrating AI technologies into sustainability-oriented decision-making and public policy, particularly within business and economics research.

The second, blue cluster captures the technical and predictive analytics dimension of the scholarly literature. Dominant keywords include “machine learning”, “forecasting”, “neural networks”, “solar energy”, “solar power generation”, “wind speed forecasting”, and “artificial neural network”. This cluster emphasizes the application of AI algorithms to forecasting renewable energy generation, improving prediction accuracy, optimizing photovoltaic systems, and supporting intelligent energy management. The close association between machine learning techniques and renewable energy technologies reflects the increasing importance of predictive analytics for improving operational efficiency and reducing uncertainty in renewable energy production.

The third, green cluster represents the smart energy systems and intelligent grid management research stream. It is characterized by keywords such as “renewable energy”, “renewable energies”, “smart power grids”, “energy management systems”, “reinforcement learning”, “microgrid”, “Internet of Things (IoT)”, and “digital storage”. This cluster illustrates the integration of AI with smart grids, distributed energy resources, and intelligent energy infrastructures. Research within this thematic area predominantly focuses on optimizing electricity distribution, enhancing grid resilience, supporting decentralized energy management, and enabling autonomous control of renewable energy systems through advanced AI algorithms.

The fourth, yellow cluster functions as a bridge cluster, which links the technical and sustainability-oriented research streams. Central keywords include “energy”, “energy efficiency”, “information

management”, “predictive analytics”, “digital twins”, “cybersecurity”, “blockchain”, and “Internet of Things”. Rather than representing a single research domain, this cluster reflects the digital transformation of energy systems, where multiple emerging technologies converge to improve energy efficiency, system reliability, and decision support. The strong connections between this cluster and the other three indicate that energy efficiency has become the central integrating concept within the AI–green energy literature. Collectively, the identified clusters illustrate the evolution of the field from isolated technological applications toward integrated research addressing sustainability, digital transformation, energy policy, and intelligent energy management. The strong interconnections among clusters further indicate increasing interdisciplinary collaboration between engineering, computer science, economics, and business research.

Overall, the keyword co-occurrence network reveals that research on AI and GE has evolved into a highly multidisciplinary field comprising four closely connected thematic domains: (i) sustainability and energy policy, (ii) machine learning and renewable energy forecasting, (iii) smart grids and intelligent energy management, and (iv) digital technologies for energy efficiency and system optimization. The high density of interconnections among clusters suggests that recent research increasingly combines technical AI methodologies with broader sustainability, economic, and policy objectives. This convergence indicates a transition from isolated technological applications toward integrated, intelligent energy ecosystems that support sustainable development, carbon neutrality, and data-driven energy governance. Such findings are consistent with the broader literature, which emphasizes the growing role of AI as a strategic enabler of the global energy transition rather than merely a technical optimization tool.

The bibliometric findings indicate that research on AI and GE has evolved beyond purely technological applications toward a broader interdisciplinary field encompassing business, economics, sustainability, and public policy. The strong interconnections between AI, renewable energy, sustainability, and energy management identified in the keyword co-occurrence network suggest that recent research increasingly views AI not only as a computational tool but also as a strategic enabler of the global energy transition. The increasing convergence of AI and GE also reflects broader economic and policy priorities. Governments and international organizations have promoted digitalization and decarbonization as mutually reinforcing strategies for achieving climate neutrality and sustainable economic growth. Consequently, research has expanded beyond engineering applications to include issues such as energy policy, green finance, environmental governance, and innovation management. The bibliometric evidence presented in this study supports this evolution, demonstrating that the field has become increasingly multidisciplinary and closely aligned with contemporary sustainability and economic development agendas.

Figure 10 presents the thematic map of the research field based on centrality and density, illustrating the conceptual structure of studies on AI and GE. The motor themes quadrant is dominated by deep learning, forecasting, and artificial neural networks, indicating that these topics are both highly developed and central to the evolution of the field. Their position reflects the growing importance of advanced AI techniques in renewable energy forecasting, optimization, and intelligent decision-making, demonstrating that predictive analytics has become one of the main driving forces behind research on sustainable energy systems.

The basic themes include machine learning, renewable energy, and smart grids, confirming their role as the conceptual foundation of the research domain. These themes exhibit high centrality but lower density, suggesting that they are widely connected to the literature while continuing to evolve through new applications and interdisciplinary research. The cluster comprising AI, sustainability, and energy efficiency occupies a transitional position, indicating an increasingly mature research direction

linking AI with sustainable development objectives. In contrast, the emerging or declining themes quadrant contains only a small cluster related to learning and machine, suggesting that few topics remain isolated or underdeveloped. Overall, the thematic structure indicates that the field is maturing, with increasing emphasis on AI-driven forecasting, renewable energy management, and smart energy systems from both technological and business perspectives.

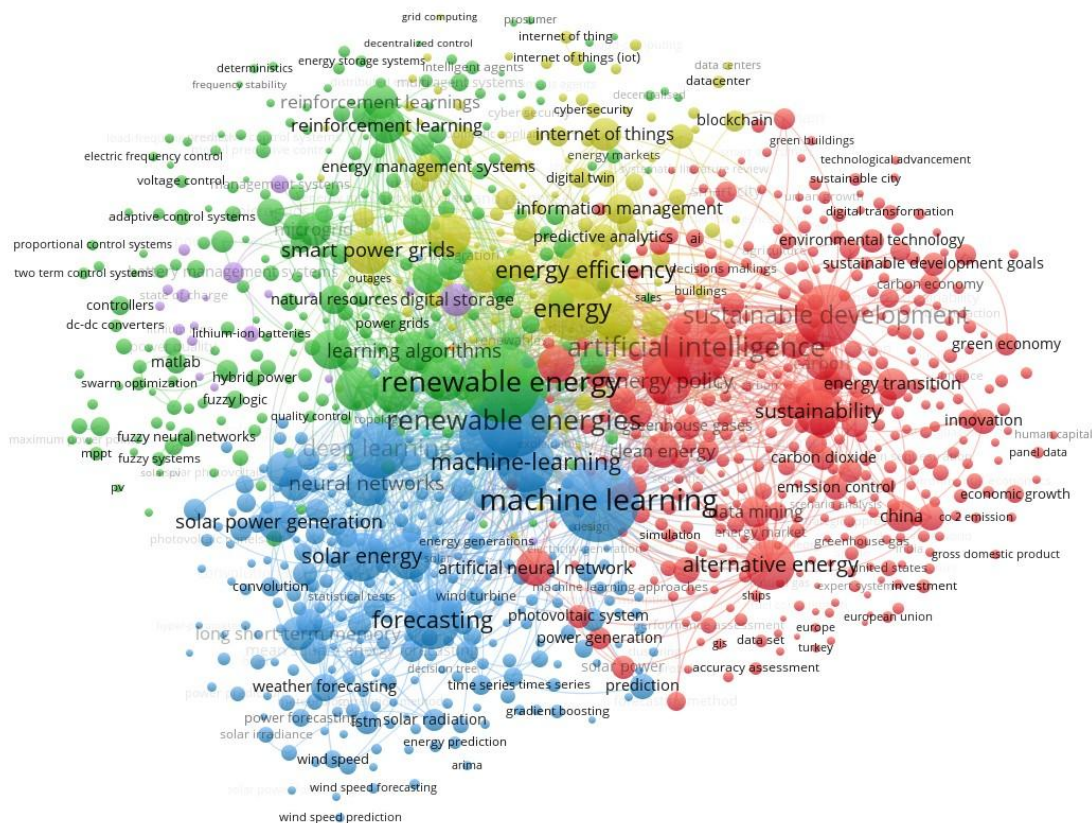


Fig. 9. Co-occurrence network

The thematic structure suggests that future research will increasingly emphasize the integration of AI with organizational decision-making, sustainable business models, and policy development rather than focusing exclusively on technological optimization.

The evolution of research topics over time is presented in Figure 11, highlighting the dynamic development of the field. Earlier studies focused primarily on decision support systems, transportation, optimization algorithms, and power systems, whereas more recent research has shifted toward AI, deep learning, machine learning, forecasting, renewable energies, and energy transition. The increasing prominence of these topics after 2022 reflects the growing integration of advanced AI techniques into renewable energy applications and underscores the transition from traditional energy management approaches toward intelligent, data-driven, and sustainability-oriented energy systems. This trend also demonstrates the expanding interdisciplinary nature of the field, linking technological innovation with business, policy, and sustainable development objectives.

The evolution of keywords demonstrates a clear shift from traditional optimization and energy management toward advanced AI techniques such as deep learning and forecasting. This transition reflects the increasing maturity of the field and the growing demand for intelligent solutions capable of supporting resilient and sustainable energy systems.

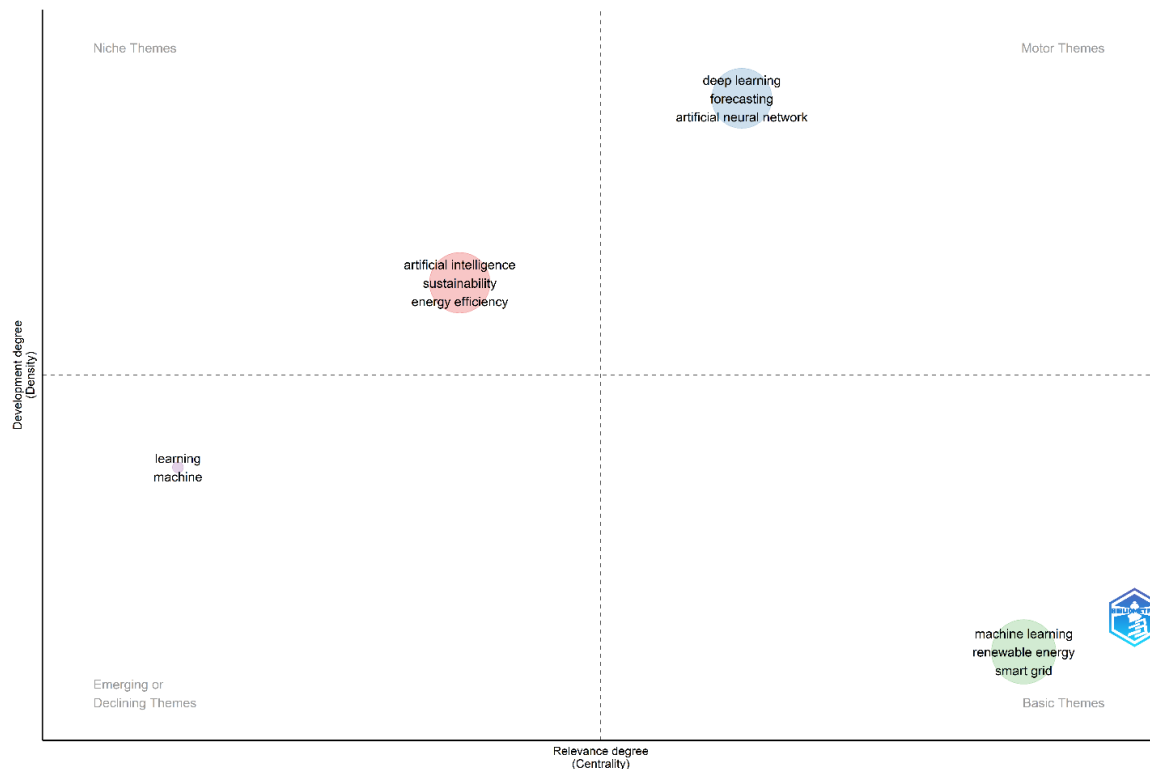


Fig. 10. Thematic map (Niches of themes in the surveyed papers)

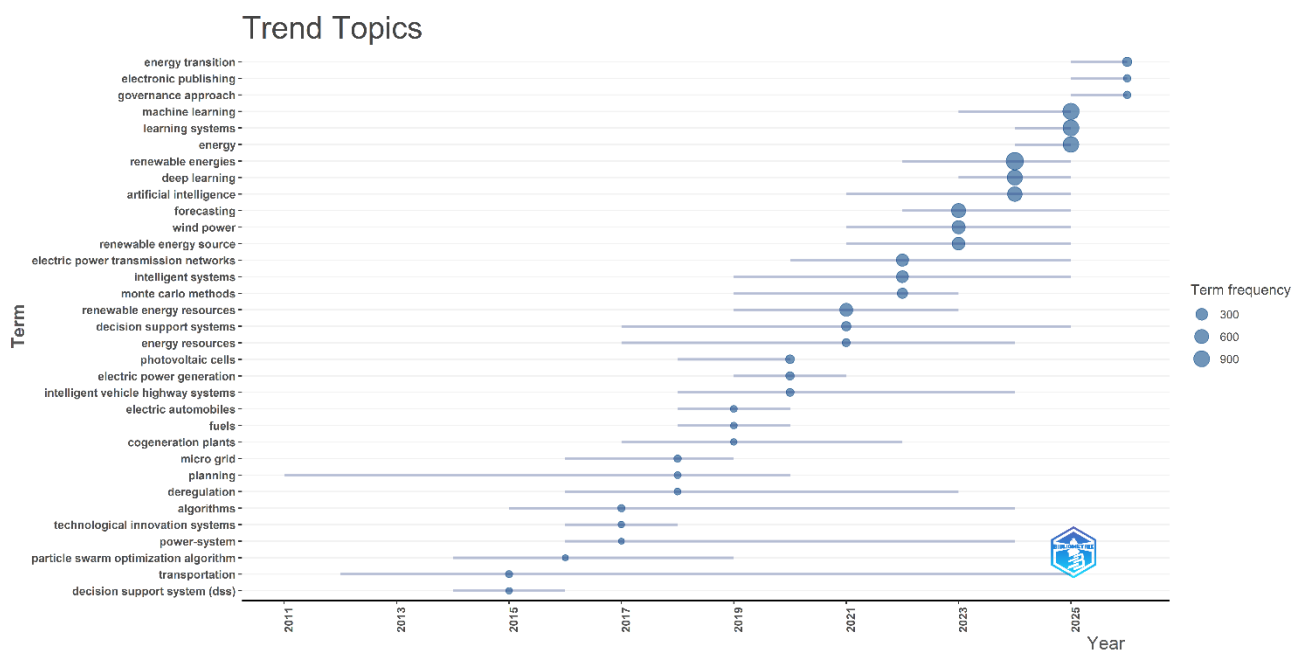


Fig. 11. Trend Topics

5. Discussion

The present bibliometric study provides a comprehensive bibliometric assessment of research at the intersection of AI and GE, demonstrating that this field has evolved from a niche research topic into a rapidly expanding interdisciplinary research domain. Beyond presenting and documenting publication trends, the findings reveal that the relationship between AI and GE extends far beyond technological innovation. The literature increasingly positions AI as a strategic capability that supports the planning, operation, and optimization of renewable energy systems while

simultaneously contributing to sustainable business practices, environmental policy, and long-term economic development. This convergence reflects the growing integration of digital transformation with sustainability objectives and highlights the expanding role of AI in supporting the global transition toward low-carbon economies.

One of the most significant findings is the rapid increase in scientific production after 2022. This acceleration is not merely the result of growing academic interest but reflects broader technological, economic, and political developments. Recent advances in machine learning, deep learning, predictive analytics, and intelligent decision-support systems have considerably expanded the practical applications of AI within renewable energy systems. At the same time, international climate commitments, including carbon neutrality strategies and energy transition policies, together with increasing public and private investment in green technologies, have stimulated interdisciplinary research linking AI with sustainable energy development. Consequently, the observed publication growth likely reflects the increasing strategic importance of AI for improving energy efficiency, supporting innovation, and facilitating evidence-based decision-making across energy markets.

The geographical distribution of scientific output further illustrates how national innovation capacity influences research development. China's scientific leadership may be associated with sustained investments in renewable energy, AI research and supportive national innovation policies.

National strategies (the Chinese government's 2022–2030 Implementation Plan that promotes technological innovation for carbon neutrality, with priorities including clean energy, low-carbon industries, carbon removal, and international collaboration) promoting carbon neutrality, digital transformation, and technological innovation have created a favorable environment for interdisciplinary research, while extensive government funding and industrial implementation of smart energy technologies have further strengthened China's scientific leadership. Similar patterns can be observed in other highly productive countries, suggesting that sustained policy support, institutional capacity, and investment in innovation ecosystems are fundamental drivers of scientific productivity within this field.

The conceptual analyses provide additional insights into the evolution of the research landscape. The co-occurrence network, thematic map, and trend-topic analysis indicate a clear transition from studies primarily concerned with technical optimization toward research integrating sustainability, business strategy, energy economics, digital transformation, and policy development. Emerging themes such as machine learning, forecasting, renewable energy integration, smart grids, and energy efficiency illustrate that AI is increasingly viewed not simply as a computational tool but as an enabling technology capable of transforming organizational decision-making and supporting sustainable business models. This evolution confirms that the field has reached a greater level of conceptual maturity and is becoming increasingly relevant to business and economics research.

Compared with previous bibliometric studies that relied on narrower search strategies or smaller datasets, the present study provides a broader representation of the field by integrating multiple AI- and renewable-energy-related terms while maintaining a business and economics perspective. Consequently, the identified thematic structure extends beyond technical optimization to include innovation management, sustainability strategy, and energy economics. Previous bibliometric studies predominantly emphasized engineering applications, whereas the present analysis demonstrates increasing integration with business strategy, digital transformation, and sustainability management. This finding suggests that the field is evolving from technology-centred research toward broader organizational and economic applications.

Despite this progress, several research gaps remain evident. Existing studies continue to focus predominantly on algorithm development and engineering applications, whereas comparatively less

attention has been devoted to organizational adoption, business value creation, governance mechanisms, regulatory frameworks, ethical considerations, and the long-term economic impacts of AI-enabled renewable energy systems. Furthermore, relatively few studies investigate how organizations successfully integrate AI technologies into strategic decision-making or evaluate the financial and managerial outcomes of these investments. Addressing these issues will require stronger interdisciplinary collaboration among researchers from engineering, business, economics, public policy, and sustainability disciplines.

The novelty of this study lies not only in the expanded search strategy and substantially larger dataset (7,301 publications), but also in its exclusive focus on the business and economics dimensions of AI-enabled GE research. The findings, on the other hand, also generate several practical implications. They suggest that organizations investing in AI-enabled energy management capabilities may improve operational efficiency, resource allocation, and sustainability performance. For policymakers, the identified research trends provide evidence supporting integrated digitalization and decarbonization strategies. For investors, the emerging thematic areas identify promising domains for future innovation and sustainable finance.

6. Conclusions

This study examined the growing body of literature on AI and GE within business- and economy-related research through a comprehensive bibliometric analysis. Using an expanded and transparent search strategy across the Scopus and Web of Science databases, a final dataset of 7,301 publications was analyzed to map the intellectual structure, scientific performance, and conceptual evolution of this rapidly developing research field. The findings demonstrate not only the remarkable growth of scientific production but also the increasing diversity of research themes, influential authors, institutions, journals, countries, and emerging research directions that collectively shape this interdisciplinary domain.

The analysis demonstrates that the integration of AI and GE is no longer solely a technological issue. Instead, it has become a strategic business and economic priority with important implications for organizational competitiveness, sustainable innovation, public policy, and long-term economic resilience. The growing convergence of AI technologies with renewable energy systems illustrates how digital transformation can support more efficient resource management, improve operational performance, facilitate evidence-based decision-making, and accelerate progress toward global sustainability objectives.

Despite the comprehensive bibliometric approach adopted in this study, several limitations should be acknowledged. The analysis was restricted to publications indexed in the Scopus and Web of Science databases, potentially excluding relevant studies available in other databases or grey literature. Only English-language publications were considered, introducing potential language bias, while the selected search terms may have resulted in keyword bias despite the substantially expanded search strategy. Moreover, bibliometric indicators are inherently affected by citation bias, whereby older publications tend to accumulate more citations than recently published studies regardless of their scientific influence. Finally, although transparent inclusion and exclusion criteria were applied, some degree of subjectivity remains unavoidable during the screening process.

Future research should continue moving beyond algorithm development toward investigating organizational adoption, governance mechanisms, explainable AI, sustainable business models, regulatory frameworks, economic impacts, and ethical considerations associated with AI-enabled renewable energy systems. Greater collaboration between engineering, management, economics, and public policy researchers will be essential for developing comprehensive solutions capable of supporting sustainable energy transitions.

Overall, this study provides one of the most comprehensive bibliometric overviews of the intersection between AI and GE within the business and economics literature. By identifying the leading contributors, conceptual foundations, and emerging research directions, it offers a robust foundation for future academic inquiry while providing actionable insights for policymakers, managers, investors, and researchers. As AI continues to reshape renewable energy systems, its successful integration will play an increasingly important role in fostering innovation, strengthening sustainable competitiveness, and supporting resilient low-carbon economies.

Author Contributions

Conceptualization, K.F.Č., D.K. and V.D.; methodology, K.F.Č.; software, X.X.; validation, K.F.Č., D.K. and V.D.; formal analysis, D.K. and V.D.; investigation, V.D.; resources, V.D.; data curation, K.F.Č.; writing—original draft preparation, X.X.; writing—review and editing, K.F.Č., D.K. and V.D.; visualization, K.F.Č.; supervision, K.F.Č., D.K. and V.D.; project administration, K.F.Č., D.K. and V.D.; funding acquisition, K.F.Č. and D.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data is available upon contact.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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