Humanities & Social Sciences Communications

REVIEW ARTICLE

https://doi.org/10.1057/s41599-024-03507-2 OPEN

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Geopolitics and energy security: a comprehensive exploration of evolution, collaborations, and future directions

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The intersection of geopolitics and energy security is a critical area of study that has garnered increasing interest from scholars around the globe. This paper employs bibliometric theory and methodologies to explore the research trajectory concerning the influence of geopolitical dynamics on energy security. Our findings, derived from both quantitative and qualitative analysis of relevant literature, reveal several key insights. Firstly, there is a notable upward trend in publications on this topic, reflecting a widespread recognition of the intricate link between geopolitics and energy security. This growing body of research aligns with the exponential growth law observed in scientific literature, showcasing a novel pattern of geographical distribution centered around energy issues. Secondly, an examination of collaboration networks at the national, institutional, and individual levels identifies China as the leading country in terms of research partnerships, positioning Chinese institutions and scholars at the forefront of this field. Lastly, our analysis delineates the research evolution within this domain through three distinct phases—pre-, mid-, and post-development stages. It highlights the shifting focus of global researchers towards the energy transition process, energy policy formulation, the stability of energy markets, and the environmental impacts of energy production and consumption. This study not only maps the current landscape of research on geopolitics and energy security but also signals the critical areas of interest and collaboration that shape this vital field of inquiry.

Introduction

Energy, as a productive resource, is essential to ensuring the productive lives of the country's citizens, it is also a strategic and politically attributed resource and plays an important role in ensuring national security and socio-economic stability (Yang et al., 2022). As the world's industrialization process accelerates, technological advances and industrial expansion continue to drive social development, the extensive demand for energy resources has triggered global concerns about energy security. The concept of energy security is initially concerned with ensuring an uninterrupted and reliable supply of energy to meet a country's or region's production needs. However, despite the importance of this issue, there is still no consensus among

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academics on a definition of energy security. This is because the concept depends on the contextual background and the different national settings (Kruyt et al., 2009). The scope of energy security is not limited to energy supply but also encompasses the stability of energy markets, the connectivity of global energy supply chains, and the sustainability of energy resources. Energy security is of paramount importance to the economic stability and growth of countries and regions. A stable energy supply is the foundation for sustaining industrial production, transportation, and daily life. Any disruption in energy supply or sharp price fluctuations will result in higher production costs and increased inflation, thereby affecting economic growth and social stability. In addition, energy security is an important component of national security. Disruptions or shortfalls in energy supplies can lead to social unrest and affect national security (Sivaram and Saha, 2018). Therefore, energy security is the key to sustaining economic growth, ensuring political stability, and promoting social well-being (Lee et al., 2022). The factors affecting energy security are multifaceted, among which the impact of geopolitical risks on energy security cannot be ignored. Geopolitics is defined as the risks associated with war, terrorism, and inter-State tensions that affects the normalization of international relations and the peace process (Lee and Wang, 2021). First of all, the political stability of energy-supplying countries has a direct impact on the reliability of their energy exports. Factors such as political instability, civil unrest, and war can lead to disruptions in energy production and transportation, thus threatening the stability of the global energy supply chain. For instance, instances of political unrest and conflict in the Middle East frequently resulted in disruptions to the oil supply, which in turn gave rise to pronounced fluctuations in the price of oil on the international market (Ben Cheikh and Ben Zaied, 2023). The ongoing conflict between Russia and Ukraine has also resulted in significant fluctuations in the prices of oil and gas (Zhao et al., 2023). Secondly, the establishment and maintenance of diplomatic relations between countries also have a significant impact on energy security. International sanctions, trade disputes, and diplomatic conflicts may restrict energy imports or exports, thereby exposing countries that are dependent on imported energy to the risk of supply shortages and price increases (Zhang et al., 2024). The relationship between Russia and the West served as an illustrative example of the manner in which geopolitical tensions can give rise to increased uncertainty regarding the supply of gas, which in turn affected Europe's energy security (Slakaityte et al., 2023). In addition, geopolitical risks include the security of energy transportation corridors, such as security threats to maritime transportation routes (Desogus et al., 2023). A significant disruption to the global energy market would result from the threat or actual blocking of important transportation corridors, such as the Strait of Hormuz or the Strait of Malacca (Meza et al., 2022). Furthermore, in the global transition to renewable energy, the deployment of renewable energy is also influenced by geopolitical risks. Countries experiencing geopolitical turmoil exhibited lower levels of domestic consumption and reduced government investment in renewable energy-related infrastructure and technology (Alsagr and van Hemmen, 2021). Despite research suggesting that geopolitics contributes to the deployment of renewable energy competition for fossil energy sources, such as oil, leads countries to seek out alternative energy sources (Ben Cheikh and Ben Zaied, 2023). The intrinsic link between geopolitics and energy security needs to be urgently addressed as countries grapple with the complexities of conserving energy resources in an environment of uncertainty.

Researches on geopolitical risk and energy security in global studies are multifaceted, and most studies used different empirical methods to shed light on the complex relationship between them. Using panel GMM and VAR models, Bin Zhang et al. empirically analyzed the impact of geopolitical risk on China's energy security from 1994 to 2021. Their findings explained the dynamic relationship between geopolitical risk and energy security, geopolitical risk didn't necessarily harm energy security and confirmed the existence of a bidirectional causal relationship between the two. In this context, the establishment of stable and fluid international relations was essential for the maintenance of national energy security (Zhang et al., 2023a). Similarly, in a recent study, Chien-Chiang Lee et al. also identified a two-way impact of geopolitical risk on energy security (Lee et al., 2024). Khalid Khan et al. investigated the causal relationship between geopolitical risk and energy security using a full-sample analysis of time series. They assessed the interaction between the two in the time dimension in conjunction with graphs of changes in geopolitical risk indicators, demonstrating that geopolitical risk was inextricably linked to energy security (Khan et al., 2023). Geotao Hu et al. used the natural discontinuity grading method to classify 102 countries around the world into energy security levels and studied the game relationship between energy security and geopolitical risk, and their study revealed the focus of the game between them (Hu et al., 2022). Indra Overland et al. addressed the geopolitical impacts that countries around the globe were likely to experience as a result of their energy transitions, proposing indicators to measure the geopolitical gains or losses of countries after the transition, and predicting the geopolitical impacts of countries after they have realized their energy transitions (Overland et al., 2019). Since the emergence of the topic of energy security and geopolitics, a considerable number of research studies have been conducted, and the number of literature reviews synthesizing the research findings has gradually increased. Early in the publication, Benjamin K. Sovacool et al. discussed definitions and metrics for energy security (Sovacool and Mukherjee, 2011). And definitions, dimensions, and metrics of energy security were examined by B.W. Ang et al. Their study identified 83 definitions of energy security that have emerged from previous literature as well as seven major themes in the field of energy security, which need to be further constructed to provide an in-depth measure of energy security (Ang et al., 2015), similarly, Abdelrahman Azzuni and colleagues conducted a comprehensive review of the literature on the definition and dimensions of energy security. Their analysis identified and categorized 15 distinct dimensions and related parameters of energy security (Azzuni and Breyer, 2018). C.J. Axon and colleagues approached the subject from the standpoint of sustainability versus risk in their examination of the role of risk in energy security assessments (Axon and Darton, 2021), Mathieu Blondeel et al. attempted to consider the energy system transition through a "whole-system" perspective, encompassing both the "high-carbon energy transition" and the "low-carbon energy transition". They also addressed geopolitical considerations pertinent to the energy system transition (Blondeel et al., 2021). The findings of research on the two subjects failed to yield consistent results. The current research lacks a structural understanding of the overall research topic. The research sub-directions are diverse and dynamic, and it is not possible to grasp the future direction of research and the emerging trends. Therefore, it is crucial to grasp the main lines of this research direction among the many studies and to reveal the focus between the different studies, this requires a systematic review of published scholarly work using a comprehensive study. The bibliometric approach is based precisely on the cross-citation relationships between literature, through emergence detection, spectral clustering, and other techniques, the conceptual trends, thematic evolution, and future development trends of the research field can be further analyzed and the pioneering achievements and key research groups in the research field can be objectively identified. Academic papers are scarce in the subject area that use bibliometric methods to explore hotspot preambles, Wei Zhou et al. conducted a bibliometric analysis of publications on energy security from 2000 to 2017, and their findings revealed the composition of research at the time, identified early features of research in the field, and suggested future research directions (Zhou et al., 2018). In a recent study, Yuyan Jiang and colleagues employed data from 2005 to 2023 to ascertain the present state and projected trajectory of recent research in the field of energy security (Jiang and Liu, 2023). Their study critically examined the content structure of scholarly publications on energy security over the timeframe of their research, and although energy security often appeared alongside geopolitical risk, their study didn't explicitly include geopolitical risk in the framework of their research, but evaluating scholarly movements following the linkage between the two. Therefore, our research employed a systematic methodological paradigm aimed at comprehensively integrating and analyzing scientific publications related to energy security and geopolitics. It was not limited to traditional bibliometric analysis, but the systematic integration and analysis of a large amount of literature through data retrieval and deep text mining techniques. Specifically, the innovations and contributions of this study are as follows. Firstly, we collected and organized scientific publications on energy security and geopolitics globally, establishing a sample literature database closely related to the research topic. Based on this sample database, we conducted a compositional analysis of the research content in this field, deeply exploring the level of scientific contributions of different research subjects (such as academic institutions, countries, research teams, etc.). This analysis revealed the research focus and academic influence of each subject in this field. Secondly, we conducted a detailed analysis of topic flows and citation networks in the literature through the use of advanced text mining and topic modeling techniques. This analysis revealed important knowledge sources and core literature within the field of energy security and geopolitics, as well as demonstrating the process of knowledge iteration. By analyzing current research trends and the dynamic changes in the citation network, it is possible to scientifically foresee the new research directions and hot issues that may emerge in the field, which provides a reference for academics and policymakers and helps to guide future research and policy development.

The remaining parts of this study are organized as follows. Section "Research method" and section "Research design" provide the research methodology and research framework of the study, which focus on the theories used in the study along with the important steps of the study. Section "Results" analyzes the results of the study, and Section "Conclusions, implications, and limitations" summarizes the full text, pointing out the shortcomings of the study and making suggestions for future research.

Research method

Bibliometrics. Bibliometrics is a comprehensive analytical technique that combines various disciplines such as statistics, informatics, and mathematics (Andrade-Valbuena et al., 2019), and it has been widely used to assess the social and intellectual roots of disciplines (Wang et al., 2021). It has been argued that, if used properly, bibliometrics can determine research funding allocations, set research priorities, map scientific developments, and reward performance. Lotka's Law, Bradford's Law, Zipf's Law, Price's Law, the law of literature aging, and the law of literature citation laid the theoretical foundations for the bibliometric development (Venable et al., 2014). This study mainly applied the six basic laws of Price's Law, Lotka's Law, and Bradford's Law to explore trends in literature growth, core author productivity, and core journals in the field.

Performance analysis. Performance analysis in bibliometric research examines the important contribution of research components to the field of study (Donthu et al., 2021). Performance evaluation of individuals, institutions, and countries by counting the number of publications owned by different subjects. The number of publications measures scientific productivity, and a high number of publications maps to high scientific productivity (Caputo et al., 2021). Furthermore, to assess the quality of publications, the total number of citations received by a publication is employed as a measurement indicator. Publications with a high number of citations are deemed to be widely recognized within the industry and to exert a considerable influence. This study first summarized the publication production patterns of geopolitical studies on energy security by calculating the annual distribution of publication levels and predicting the growth trajectory of future publications, then followed by computational analysis of trends in the geographical distribution of national publications, institutional publications and authors' publications, evaluating the research contributions to the field from macro, meso, and micro perspectives.

Collaborative network analysis. Collaborative research is an important form of scientific research, a behavioral activity undertaken by researchers to achieve the goal of producing new scientific knowledge, it facilitates cross-fertilization of different disciplines and promotes the generation and development of new knowledge (Lee and Bozeman, 2016). Collaborative research is usually presented in the form of co-authored papers, where researchers affiliates with different countries and institutions work together to produce knowledge (He et al., 2021). Scientific collaboration enhances the quality of research outputs, as evidenced by studies indicating that collaborative publications are cited more often than those created alone, especially for highly internationalized research papers (Adams et al., 2018; Gorraiz et al., 2012). In other words, a research paper will be more widely recognized in the field if it is co-authored by multiple countries and multiple authors. This study examined the structure of research based on the static attributes of the research scholars, which reflected the identity attributes of the researchers within the academic field, including the researchers' institutions and countries (Liu et al., 2024). Consequently, both national and institutional collaboration are founded upon the basis of author collaboration, which represents the most fundamental unit of collaboration. The visualization of collaboration between research scholars, research institutions, or countries is presented through the collaboration network. Collaborative network is an undirected network used to describe inter-subjective collaborative relationships and patterns based on collaboration conducted by different researchers, nodes in a network represent research individuals, such as nodes in a country collaboration network represent country attributes. Node size represents the number of publications, and the connecting lines of the nodes usually indicate the collaboration between different subjects, and the thickness of the connecting lines correspondingly indicates the intensity of collaboration, if the collaboration between two subjects is more frequent, then it is represented as a thicker connecting line (Jin et al., 2020). The process by which scientific research collaboration is formed is illustrated in Fig. 1.

This study mapped country collaborative networks, institutional collaborative networks, and author collaborative networks to explore whether differences in geographic location played a role in international collaborative behavior, as well as to reveal the number and characteristics of institutional and author collaborative groups in the area.

Keywords analysis. In bibliometric studies, article keywords are often used to identify the main research and hot topics, for keywords are important textual elements that summarize the main research content of a scholarly publication (Li et al., 2016), the frequency of occurrence of a keyword reflects the importance of the word in the text, high-frequency keywords often represent important topics. The distance between keywords reflects the relevance of different keywords, with higher-relevance keywords

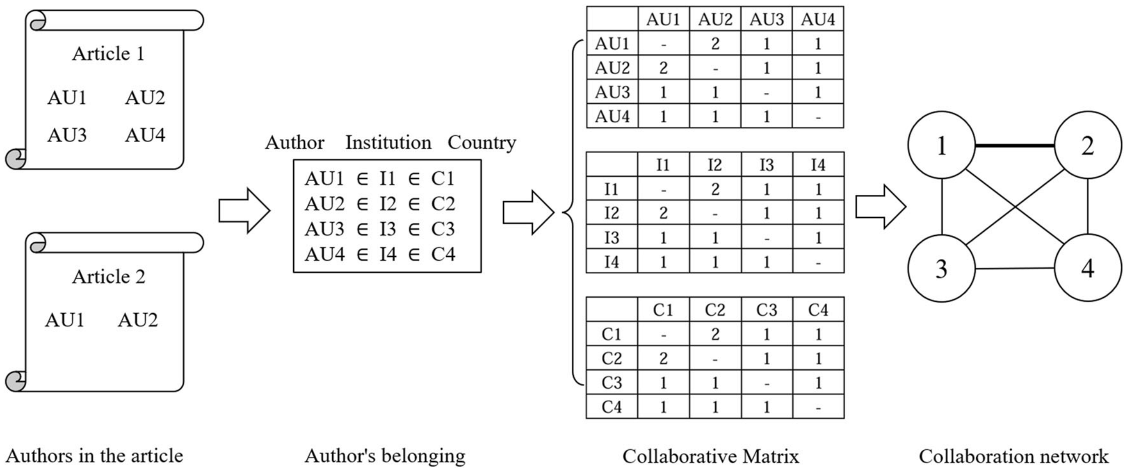

Fig. 1 Formation of collaborative network for scientific research. This figure shows the process of collaboration formation: on the far left is the number of authors in the article, followed by the authors' affiliations, then followed by a collaboration matrix based on the authors' collaborations in the article, and on the far right is the collaboration network based on the matrix.

clustered closer to each other and forming keyword clusters (Huang et al., 2019). Different clusters of keywords map different topics in the research field. Therefore, to identify the distribution of core themes in the study of geopolitical impacts on energy security and their evolutionary paths, we used the keyword co-occurrence method to analyze the co-occurrence of keywords from all the collected literature and explored the resulting keyword clusters in depth to identify future research directions and research focus in the field.

Science mapping analysis. Data visualization can intuitively express important node information such as group structure in a network, and is an important characterization method for processing large amounts of data. VOSviewer provides visualization of the similarity of node distances, allows users to create networks of countries, institutions, and author collaborations, and provides three network graph representations: clustering view, time view, and density view (van Eck and Waltman, 2010), and it can handle large amounts of literature data (Van Eck and Waltman, 2007). In this study, we used VOSviewer to map collaborative network, literature citation network, and keyword co-occurrence network, during the threshold setting process, we chose the full-count method, in which a paper co-authored by two subjects is attributed to each author in the paper, and the smallest unit in the network was also set to be 1, which can fully demonstrate the structure of knowledge collaboration and actors in the research field of this topic, and then clustering view and temporal view of collaborative network were formed. Gephi was used to map the performance networks of institutions and journals, it offers several layout methods to display network graphs according to their weights (Bastian et al., 2009). In addition, we used a bibliometric package in the Rstudio programming (Aria and Cuccurullo, 2017) to obtain accurate information on the distribution of literature. Also, the statistical analysis of this study was calculated by Microsoft Excel.

Research design

Data sources and processing. In this study, the basic bibliographic information was obtained from the core collection of the Web of Science (WOS), Science Citation Index Expanded (SCI-EXPANDED), Social Science Citation Index (SSCI), Arts and Humanities Citation Index (AHCI), Conference Proceedings Citation Index (CPCI-S), and Emerging Sources Citation Index (ESCI) are included in the core collection, which is widely used in bibliometric studies. The definition of energy security is of great importance in identifying search terms, as it delineates the crucial aspects of energy security and its scope. However, the definition of energy security is context-dependent and subject-dependent and has not yet resulted in a concept that is uniformly used in the industry (Kruyt et al., 2009). The historical definitions of energy security have initially focused on the stability of access to fossil fuels, particularly oil (Strojny et al., 2023). The increased use of natural gas and other fuels, such as coal, has also expanded the scope of energy security. The distribution of fossil fuels has led to the gradual inclusion of economic attributes in the attributes of energy security, as oil has become a globally traded commodity (Jenny, 2007; Wang et al., 2022). Energy prices, energy trade, and the stability of energy markets all play a crucial role in energy security. Secondly, the energy trading process is susceptible to the risk of supply chain disruptions due to the inherent vulnerability of energy supply chains to transportation risks, particularly given the considerable distances over which energy is transported (Scheepers et al., 2006; Spanjer, 2007). Security of energy supply has also become an important part of energy security concerns. Finally, in the process of energy transition, the transition from fossil energy to clean energy requires ensuring the stability and continuity of clean energy supply. At the same time, based on geopolitical considerations of energy security, energy cooperation may be effective in minimizing geopolitical conflicts due to the competition for energy resources and in ensuring the security of energy supply. Accordingly, the selection of keywords in this section was comprehensive and aligned with the fundamental elements of the conceptual framework of energy security, including "energy security", "energy risks", "energy supply risks", "energy cooperation", "energy transition", "energy transportation", "energy markets", "energy price", "energy trade" as search keywords. Subsequently, we broke down the term "energy" in "energy security" according to the nature of the energy source, subdividing it into "coal", "oil", "natural gas", "electricity", "wind", "nuclear", "water energy", while adding "renewable energy" and "clean energy" on this basis. The combination of these two subsections of keywords constituted a searchable formula for the retrieval of academic results that were closely related to the topic of "energy security". The second section concerned subject words related to geopolitical risk, as investigated by Jiangli Yu and Ahmet Faruk Aysan et al. (Aysan et al., 2023; Yu et al., 2023), the keywords of geopolitical risk were set as "geopolitical risk", "geopolitics", "international conflict", "international geopolitics", and "geopolitics". To retrieve data, the search field designated as "Topic" was utilized, which means a topic search is conducted within the article's title, abstract, keywords, and keywords plus. Data was accessed on January 7, 2024, and the period was set to all years. To obtain a high-quality data source, we first restricted the publication types, conference papers, editorial materials, letters, notes, book chapters, and book review types of articles were excluded, and only articles and review articles were included in the study, followed by restricting the language to English. Then we analyzed the titles and abstracts of the retrieved papers, and in some cases, even the entire contents of some papers, to determine whether each paper focused on the topic. It's worth mentioning that even though we tried to find the most relevant papers through the search strategy described above, there were still some irrelevant papers because different authors have their own styles to highlight their articles. Ultimately, we obtained 429 papers for the bibliometric analysis.

Research framework. The occurrence of geopolitical events has had a significant impact on global energy activities, economic trade, and cooperative exchanges. This study utilized data from literature titles included in the Web of Science core collection to examine the impact of geopolitical risk on energy security. Breaking away from the traditional method of organizing a literature review, this study provided an in-depth analysis of the impact of the presence of geopolitical risks on the research field of energy security in terms of the historical development of publications, the geographical distribution, the scientific collaboration, the evolution of the knowledge base and research hotspots in this research field.

The traditional literature review is a method of summarizing and evaluating the existing literature in a particular field of study. This is typically conducted by a researcher who selects, reads, and summarizes relevant literature based on their research experience and expertise (Cronin, 2011). Its purpose is to provide background information on a research topic, demonstrate the progress of research in the field, and identify major research findings, theoretical perspectives, and problems, thereby providing references and insights for further study (Li and Wang, 2018; Rozas and Klein, 2010). The absence of strict procedural constraints in a systematic and standardized process may result in the researcher's subjective bias influencing the selection and evaluation of literature, thereby reducing the reliability and comprehensiveness of the results of the review. In contrast, the bibliometric method is founded upon the external characteristics and internal connections of the literature. It is based on a series of rigorous procedures for the inclusion and exclusion of literature, as well as general research steps, which are employed to study the temporal distribution, quantitative characteristics, and patterns of change of a given topic. It incorporates a greater quantity of literature, employing mathematical and statistical methods to analyze the research profile of a given topic at a macro level (Kirby, 2023). Furthermore, bibliometric offers a significant advantage in the analysis of citation relationships among literature, which is not feasible within a limited timeframe with a traditional literature review. The bibliometric builds citation-coupling networks, co-citation networks, collaborative networks, and co-occurrence networks in the literature, which can predict future research directions in the forward direction, analyze the knowledge base underlying the subject area in the backward direction, and dynamically present the thematic evolution of the research field, as well as identify outstanding contributors and important literature in a particular field (McBurney and Novak, 2002; Ninkov et al., 2022). In conclusion, the traditional literature review is concerned with the analysis of the research content and findings presented in the literature, to summarize and analyze previous research and identify future research directions. Instead, bibliometric is more concerned with the analysis of the distribution and change of research results in a given field. The research results in a certain field can be assessed regarding the number of research and citation relationships. This allows for the impact of academic research to be evaluated, the academic frontiers and hotspots to be discovered, and research management and decision-making to be facilitated. Therefore, this paper referred to the methodology of F. De Felice et al. using hierarchical analysis for the analysis and discussion of the bibliometric study (De Felice et al., 2018), specifically, structured modeling was carried out according to the following four steps:

First, identify the research objectives and the research questions to be addressed. During this stage, the research perspective was further focused on the field of energy security through extensive reading on the impact of geopolitical risks on global economic trade, energy activities, education, and scientific research cooperation.

Second, select the research methodology. By breaking down the research questions and research objectives, the appropriate research methodology was selected, along with the time and scope of the study.

Third, identify keywords and construct a search formula. In this stage, by discussing with experts and scholars and reading the basic research about the field, we extracted the representative key phrases of the research field, constructed the search formula, searched in the database, and de-weighted and cleaned the data.

Fourth, data visualization and analysis. After data collection and data cleaning, the data were calculated, and through various data visualization tools, the collected literature data were visually characterized and analyzed to visualize and understand the development trend, distribution range, and research status of the research field. The roadmap of the research conducted in this study is shown in Fig. 2.

Results

Descriptive statistics of literature information. The basic information about the literature data used in this study is given in Table 1. The study period runs from 2003 to 2023 and involves a total of 429 publications from 135 journals, with an average half-life of publications of 4.04 years, 19,847 references are cited in these publications. In addition, the author's keywords and keywords plus used to conduct topic exploration are identified 1136 and 732 respectively, through which the article analyzed the main research trends in this research area. In publications studying the impact of geopolitics on energy security, 1001 authors are involved in the process of knowledge creation, of which 73 authors conducte their research independently.

Publication trend. Thomas Kuhn in *The nature of scientific revolutions* proposed that the process of scientific development is a "primitive science" to "conventional science" transformation, as well as the transition from one "conventional science" to another "conventional science" process. It was divided into several stages: the scientific development of the pre-scientific, conventional science, scientific crises, scientific revolutions and the new conventional science. The formation of a discipline has undergone a theoretical accumulation of the formation of the paradigm to the paradigm of paradigm change, and then produce a new paradigm of the process of the entire process of scientific development under the impetus of scientific revolutions, the entire scientific development process of the continuous cycle of development (Kuhn, 1970). Price's proposed literature growth curve is consistent with Thomas Kuhn's theory of scientific development, he believed that the growth of the literature shows a logical growth trend of the "S" curve, but the growth of the literature is not endless and will eventually stop at a certain K (Price, 1963). The mathematical expression for the theoretical model of the

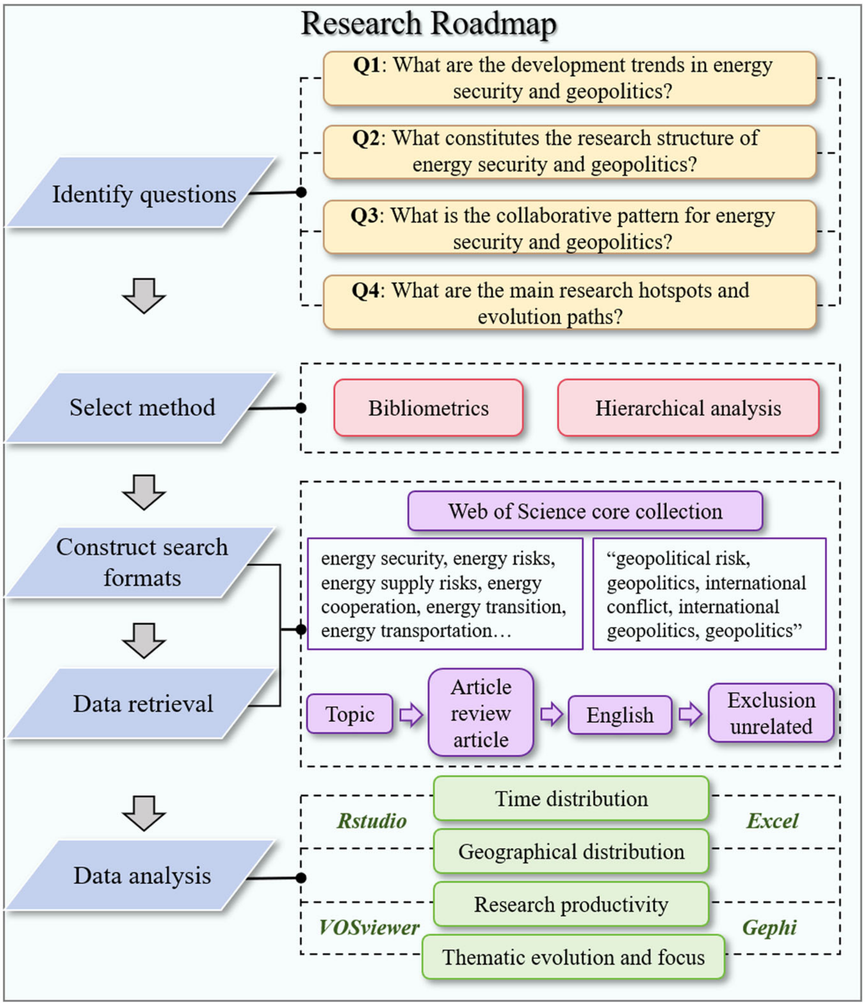

Fig. 2 Research roadmap. This figure depicts the research roadmap of this paper. The right side of the figure illustrates the research content of this paper while the left side depicts the research process corresponding to the research content of this paper.

Table 1 Main information about data.

Project	Description	Results
Basic information	Timespan	2003–2023
	Sources (Journals, Books, etc.)	135
	Documents	429
	Annual growth rate %	5.37
	Document average age	4.04
	Average citations per document	23.91
	References	19847
Document information	Keywords plus (ID)	732
	Author's keywords (DE)	1136
Author information	Authors	1001
	Authors of single-authored documents	73
	Single-authored docs	80
	Co-Authors per document	2.87
	% of international co-authorship	37.53

literature growth by the logistic curve is shown below:

$$F(t) = \frac{k}{1 + ae^{-kbt}},\ k, a, b>0 \quad (1)$$

where $F(t)$ is the literature accumulation for the year, t is the time, k is the literature accumulation when the time tends to infinity, and is the maximum value of the literature accumulation, and a, b are the conditional parameters.

To examine trends and forecast future developments in the growth of publications related to geopolitics and energy security, and to test whether the growth of the literature in this area conforms to a logistic growth curve, we fit a logistic to the annual cumulative publications. The trend in annual cumulative publication growth was first fitted using Excel, and it was found that the cumulative literature was optimally fitted according to the exponential, which got $R^2 = 0.9873$. Subsequently, according to the curve trend to take $k = 90{,}000$, to determine $a = 1.9$ when the most consistent with the cumulative curve, at this time to get $b = 0.2576$, and ultimately got the logistic growth curve as shown in Fig. 3, the cumulative annual growth in the number of publications in the field of research in line with $y = 1.9e^{0.2576t}$. Comparison with the logistic growth curve reveals that the growth of literature in the field is currently in the pre-growth phase of the logistic curve and may reach the horizontal phase of the logistic curve after the next few decades. In the pre-growth phase, the annual number of publications increases significantly in 2022–2023, from 65 to 135, probably due to the impact of the Russia–Ukraine conflict in 2022, which has redirected people's attention to the study of geopolitics and energy security.

Geographical spatial distribution. Spatial analysis of geographic distribution can reveal collaborative networks related to the

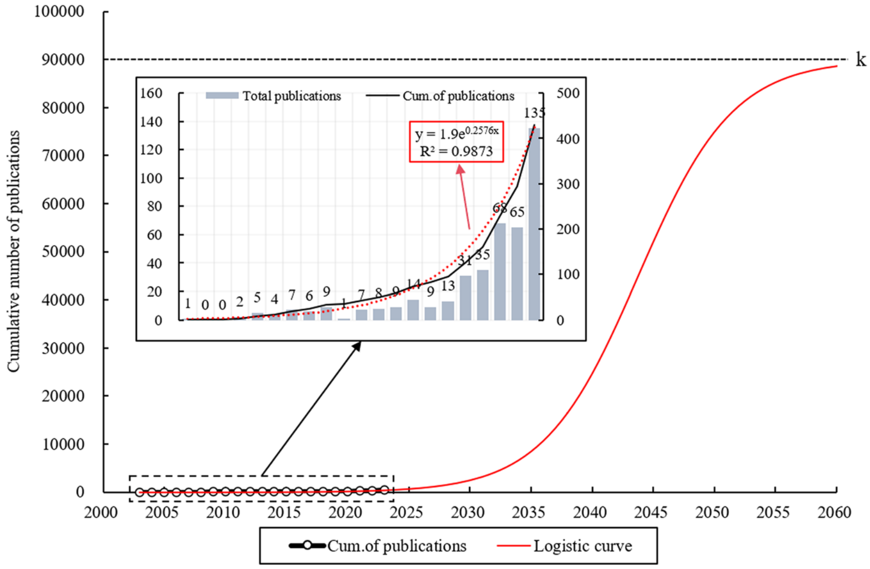

Fig. 3 Trends in literature growth of geopolitics and energy security studies. This figure illustrates the growth trend of literature in the study area, with the horizontal axis representing time and the vertical axis indicating the cumulative number of publications. The smaller part of the graph depicts the detailed trend of annual and cumulative numbers of articles published.

geographic distribution of publications. Therefore, Scimago and VOSviewer were combined to map the geographic collaborative network of national issuance volumes. A geo-visualization network of the distribution of publications and the collaboration between countries is shown in Fig. 4a and b. The area of the circles in the graph indicates how many publications there are, with larger circles representing more publications, and the connecting lines between the nodes of the different circles indicating the collaboration between countries. In terms of the geographical distribution of publications, countries in Asia, Europe, Australia, and the Americas make the greatest contribution to this field. Among Asian countries, China coveres 168 publications and have the highest number of publications in this field, followed by the United Kingdom (60), the United States of America (43), Germany (26), and Turkey (24). Most of the countries in Europe are involved in research outputs in this area, in addition to countries in the Middle East, which may be attributed to the increased interest in research related to oil security in the region due to resource abundance.

Nevertheless, an exclusive emphasis on the number of national publications to assess a country's scientific output is inadequate. The quantity of publications in a country merely reflects its quantitative capacity, without incorporating the quality of these publications into the evaluation. Therefore, considering the availability of data, we counted the total number of citations of the countries through VOSviewer, ranked the two indicators, the number of publications of the countries and the total number of citations by entropy-weighted TOPSIS, and evaluated them using SPSSAU (project. T S, 2024), which evaluates the 67 countries that participated in the publications. The entropy-weighted TOPSIS initially identifies the positive and negative ideal solution values (A+ and A−) for the evaluation indexes. Thereafter, the distance values D+ and D− are calculated for each evaluation object concerning the positive and negative ideal solutions, respectively. Finally, the proximity of each evaluation object to the optimal solution (*C*) is determined, and the C is ranked. The final ranking of the top 10 countries is presented in Table 2.

As illustrated in the accompanying table, the composition of the top ten countries differes when considering both the quantity and quality of publications. China retains its position at the top of the list, with 168 publications garnering 3608 citations from scientists across the globe. The reasons may be explained in the following ways. Firstly, as the world's largest energy consumer, China's rapid economic growth has led to an ever-increasing demand for energy, which has driven a significant number of studies and publications on energy security and geopolitics. Secondly, the Chinese government attached great importance to energy security and geopolitics and has formulated a series of policies and strategies, as well as provided strong support and funding to promote research and development in related fields. Furthermore, China is a highly active participant in international collaboration and academic exchanges. With the advancement of the Belt and Road Initiative, China's influence in the global energy market is increasing, which has led to a significant increase in the international attention and citation value of its research results. The second-ranked country is the United Kingdom, which has a total of 60 publications with a total of 2139 citations, and the third-ranked country is Pakistan, which has 22 publications with a total of 1407 citations.

In the national collaboration on publications, the study of geopolitics on energy security involves a total of 67 countries around the world, of which 59 countries have collaborative relationships. From the chord diagram of international research collaboration, the depth of the color of the connecting lines between countries indicates the intensity of their collaboration. In Fig. 4c, the color of the connecting line between China and the United Kingdom, the United States, Romania, Saudi Arabia, Turkey, Spain, and Vietnam is red, which indicates that the intensity of collaboration between China and these countries is higher than that between other countries and that China has more partners and higher collaboration credits in this field of research. In addition, it is found that the geographic distribution of articles in studies of geopolitics and energy security shows a clear energy-oriented country or geopolitical risk-oriented country, unlike previous academic research, the main geographic distribution of publications in this subject area is concentrated in energy-rich or geopolitically risk-intensive areas, gradually moving away from the geographic distribution trend where the level of economic development leads to the distribution of scientific research.

Contribution of institution. In terms of meso-institutional collaboration, a total of 686 institutions around the world are involved in the research, forming a large network of institutional collaboration.

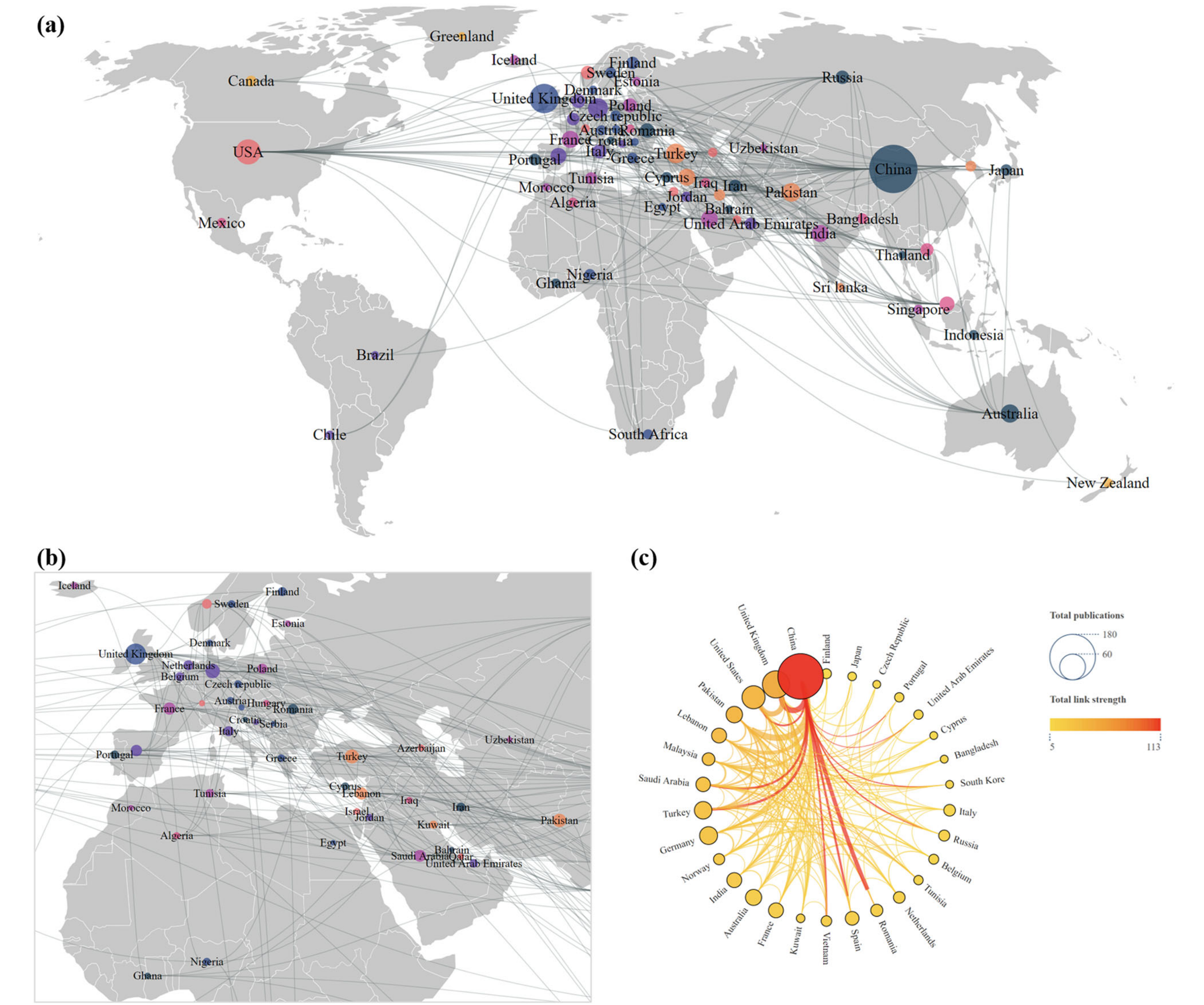

Fig. 4 Geo-visualization and geo-distribution mapping of collaborative networks. a Global geographic distribution of publications and collaboration networks. **b** Localized zoomed-in view of the collaboration network. **c** Chord map of the intensity of country collaboration. This figure illustrates a geographic network of collaboration in the field of geopolitics and energy security. Nodes indicate countries, with size indicating the number of country postings. Connecting lines indicate collaborations between countries. **a** indicates the global collaboration network of countries, **b** indicates the detailed collaboration networks in Europe, northern Africa, and western Asia, and **c** indicates the country collaboration chord map.

Table 2 Top 10 countries by entropy weights TOPSIS.

Rank	Country	Positive ideal solution distance (D+)	Negative ideal solution distance (D−)	Relative closeness (*C*)
that	participated in the 1955.475	publications1 1	China	0
2	UK	797.102	1158.729	0.592
3	Pakistan	1193.868	762.046	0.39
4	Saudi Arabia	1372.454	583.314	0.298
5	USA	1436.839	518.638	0.265
6	Australia	1503.819	451.76	0.231
7	Netherlands	1547.309	408.368	0.209
8	Norway	1702.064	253.487	0.13
9	Turkey	1710.985	244.495	0.125
10	Germany	1715.297	240.188	0.123

The number of publications and the collaboration between them is shown in Fig. 5. As can be seen from Fig. 5, Qingdao University (China) has an outstanding research performance in this field, with 23 publications and a total of 782 citations. Meanwhile, Qingdao University has formed collaborative relationships with 33 domestic and foreign organizations, and the intensity of collaboration is 53. These institutions include the Lebanese American University, the Central University of Punjab, and the University of Southampton. The organizations within China are Qilu University of Technology, Southwest Jiaotong University, and Anhui University of Finance and Economics. The study of geopolitical impacts on energy security has resulted in 27 collaborative groups, which have worked together on a wide range of research topics.

Contribution of author

Core author distribution. Lotka's Law describes the distribution of the frequency of scientific productivity: in a given field of

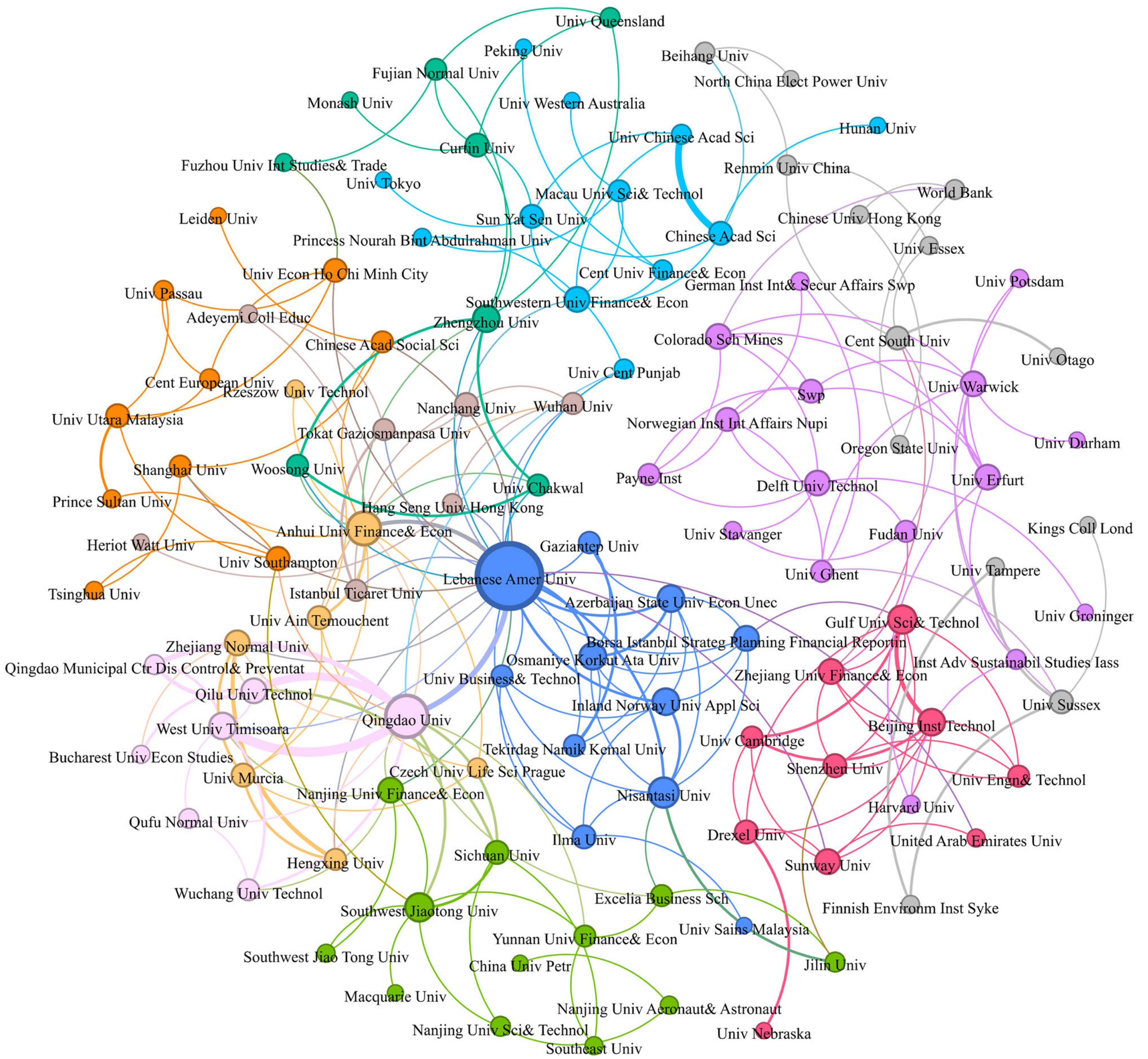

Fig. 5 Institutional collaboration network. This figure depicts a collaborative network of institutions. Nodes represent institutions, and lines between nodes indicate collaborative relationships between institutions. Nodes of the same color indicate similar research content.

study, the number of authors writing n papers are approximately $\frac{1}{n^2}$ of the number of authors writing 1 paper. The proportion of all authors writing 1 paper to the total number of authors is approximately 60% (Lotka, 1926; Tsai, 2015). To test whether Lotka's Law applies to this field of study, we analyzed it using Lotka's Law and verified the reliability of the law using nonparametric hypothesis testing. The K–S test is a useful nonparametric hypothesis testing method that is primarily used to test whether a set of samples comes from a certain probability distribution. We followed the following steps to test.

(1) Firstly, the data used for the calculations were prepared according to Table 3, which shows the number of authors with x publications, the total number of publications, the cumulative number of publications and the cumulative number of authors, as well as the cumulative percentage.

(2) Secondly, the data in Table 4 were used to calculate the exponent of Lotka's Law, which was calculated from the least squares formula:

$$n = \frac{N\sum XY - \sum X\sum Y}{N\sum X^2 - (\sum X)^2} = -2.6636 \tag{2}$$

Thus, the absolute value of the exponent n is between 1.2 and 3.8, in accordance with Lotka's Law.

(3) Subsequently, c and critical value were calculated by the following equation:

$$c = \frac{1}{\sum_1^{p-1}\frac{1}{x^n} + \frac{1}{(n-1)p^{n-1}} + \frac{1}{2p^n} + \frac{n}{24(p-1)^{n+1}}} \tag{3}$$

$$\text{critical value} = \frac{1.63}{\sqrt{\sum Y}} \tag{4}$$

Calculated to get $c = 0.7907$, critical value $= 0.3781$.

Table 3 Calculation of author productivity.

Publications	Authors	Total publications	Cumulated publication	% of Cumulated publication	Cumulated author	% of Cumulated author
1	886	886	886	71.92	886	87.46
2	85	170	1056	85.71	971	95.85
3	26	78	1134	92.05	997	98.42
4	6	24	1158	93.99	1003	99.01
5	5	25	1183	96.02	1008	99.51
7	2	14	1197	97.16	1010	99.70
10	1	10	1207	97.97	1011	99.80
11	1	11	1218	98.86	1012	99.90
14	1	14	1232	100.00	1013	100.00

Table 4 Calculation of exponent *n*.

Publications	Authors	*X* = ln (Publicaions)	*Y* = ln (Authors)	*XY*	*XX*
1	886	0.0000	6.7867	0.0000	0.0000
2	85	0.6931	4.4427	3.0794	0.4805
3	26	1.0986	3.2581	3.5794	1.2069
4	6	1.3863	1.7918	2.4839	1.9218
5	5	1.6094	1.6094	2.5903	2.5903
7	2	1.9459	0.6931	1.3488	3.7866
10	1	2.3026	0.0000	0.0000	5.3019
11	1	2.3979	0.0000	0.0000	5.7499
14	1	2.6391	0.0000	0.0000	6.9646
Total	-	14.0729	18.5818	13.0818	28.0025

Table 5 Kolmogorov-Smirnov test, *n* = 2.6636.

Author publication productivity	Authors	Accumulated author	Observed valued	Accumulated observed value $S_n(x)$	Expected value	Accumulated expected value $F_O(x)$	*D*
1	886	886	0.8746	0.8746	0.7907	0.7907	−0.0839
2	85	971	0.0839	0.9585	0.1248	0.9155	−0.0430
3	26	997	0.0257	0.9842	0.0424	0.9579	−0.0263
4	6	1003	0.0059	0.9901	0.0197	0.9776	−0.0125
5	5	1008	0.0049	0.9950	0.0109	0.9884	−0.0066
7	2	1010	0.0020	0.9970	0.0044	0.9929	−0.0041
10	1	1011	0.0010	0.9980	0.0017	0.9946	−0.0034
11	1	1012	0.0010	0.9990	0.0013	0.9959	−0.0031
14	1	1013	0.0010	1.0000	0.0007	0.9966	−0.0033

(4) Finally, a nonparametric hypothesis test K–S test in Table 5 was conducted to test the reliability of Lotka's Law.

$$D = \mathrm{Max}|F_O(x) - S_n(x)| = 0.0839 \quad (5)$$

Therefore, the absolute value $D_{max} = 0.0839 < 0.3781$ was calculated by the above steps, and hence it can be concluded that Lotka's Law is valid in this subject area.

Co-author network. From the above analysis, it is clear that the author-output pattern of geopolitical impact on energy security is consistent with Lotka's Law, to further explore patterns of author collaboration in this area, we used VOSviewer to map the network of author collaborations.

As shown in Fig. 6, there are 13 author collaborations in academic publications that examine the impact of geopolitics on energy security. One of the outstanding contributing authors in the field is Su Chi-Wei, who has contributed 14 scholarly publications and forms a collaborative cluster with 40 other authors. This is followed by Khan, Khalid (11 publications) with collaborative links with 32 authors, Umair, Muhammad (10 publications) with academic collaborations with 28 authors, and Qin, Meng, and Ma, Feng who have the same number of publications, both contributing 7 articles to the academic community. But Ma, Feng has more collaborations with other researchers, collaborating with 23 researchers, while Qin, Meng has collaborations with 21 authors. As shown in (a) of Fig. 6, among the top 5 authors in terms of number of publications, three authors are from China. In addition, from the time plot of the authors' publication volume and collaborative networks, the node colors are dark to light indicating that the authors published their research papers from far to near. The collaborative cluster of authors led by Ma, Feng has a long-standing interest in this research area, with their research focusing on the market impact of uncertainty in geopolitical risk and volatility in crude oil prices. Su chi-wei, Khan, Khalid, Umair, Muhammad, and Qin, Meng are late researching this area. Their team published papers between 2021 and 2023 that examined the interactions between renewable energy, the energy transition, oil prices, and geopolitical risks. These contributions

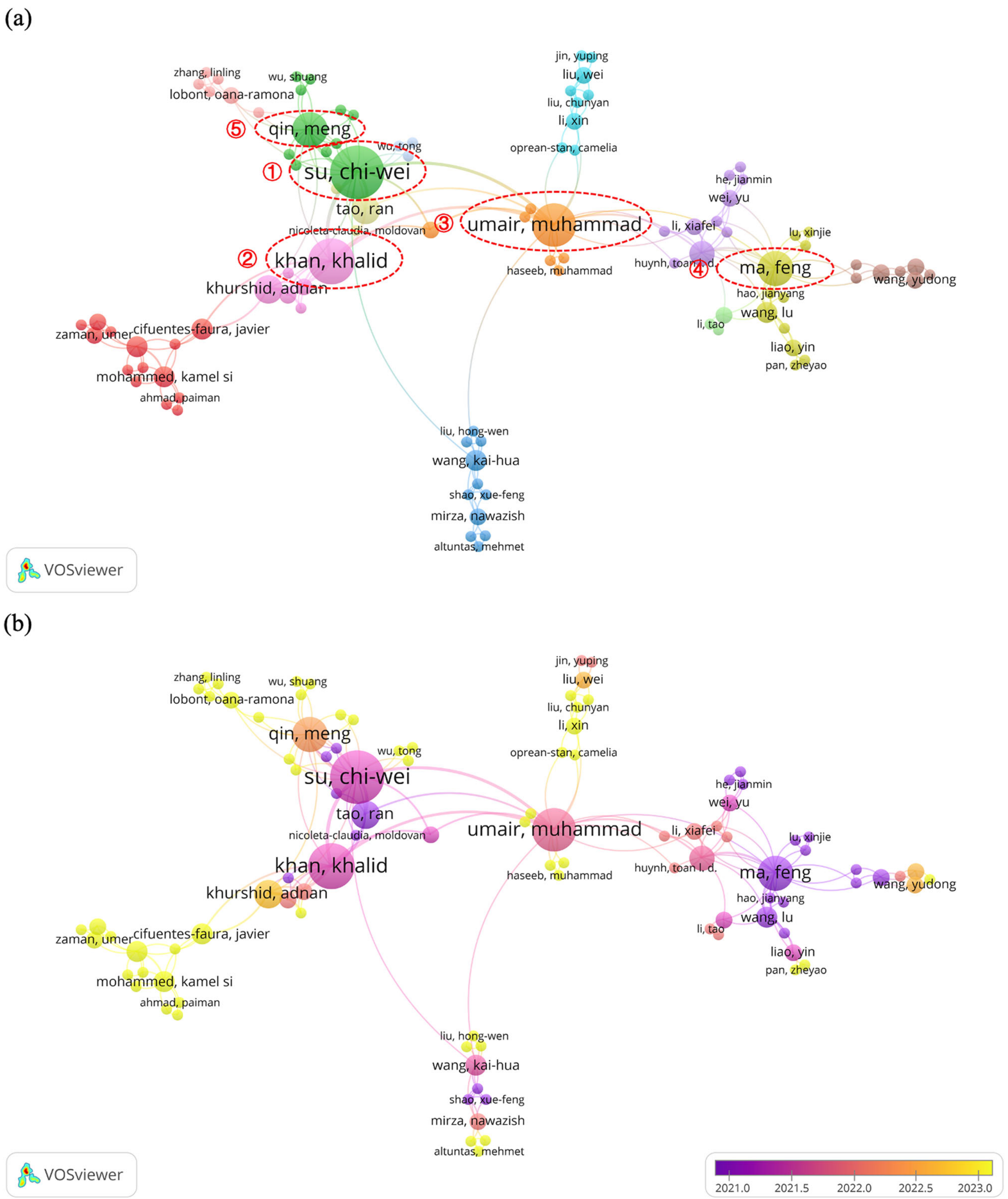

Fig. 6 Author collaboration network. a Collaboration network of the top 5 authors in terms of number of publications. **b** Author collaborative evolutionary networks. This figure depicts the authors' collaborative network and its temporal evolution. Nodes represent authors, and connecting lines between nodes indicate collaborative relationships between them. Nodes of the same color indicate similar research content.

have helped to advance the field. It can also be seen in Fig. 6 that in the fringe group of the author collaboration network, the fringe authors tend to be publishers of recent publications and have not yet formed larger collaborative clusters and these fringe authors may be transformed into center authors in future studies.

Contribution of journals. The geopolitical impact on energy security cuts across multiple disciplinary areas and has been analyzed from multiple publications, with the contribution of journals to the field assessed through the number of articles published in them. Information on the types of journals that ranks among the top 10 by the number of articles published in the field is shown in Table 6.

Table 6 Information on the top 10 journals by publications.

Journal	Publisher	Countries	Publications	IF 2022
Resources Policy	Elsevier	England	66	10.2
Energy Policy	Elsevier	England	33	9
Energy Economics	Elsevier	Netherlands	27	12.8
Energy Research & Social Science	Elsevier	Netherlands	17	6.7
Energy	Pergamon-Elsevier	England	16	8.9
Geopolitics	Routledge Journals, Taylor& Francis	USA	14	2.9
Finance Research Letters	Academic Press Inc. Elsevier Science	USA	13	10.4
Energies	MDPI	Switzerland	11	3.2
Environmental Science and Pollution Research	Springer, Heidelberg	Germany	10	5.8
Renewable Sustainable Energy Reviews	Pergamon-Elsevier	USA	10	15.9

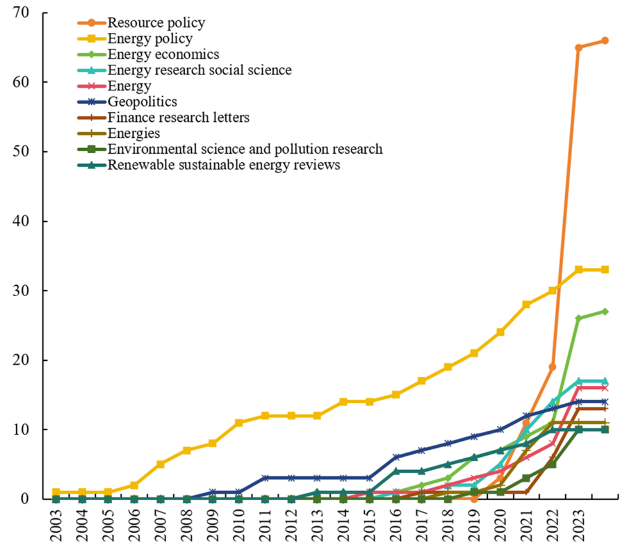

Fig. 7 Annual change of journal publications. This figure illustrates the annual publication trend for the top 10 journals in terms of the number of articles published. The horizontal axis represents the year while the vertical axis depicts the number of articles published by the journal.

Resources Policy has the highest focus on the topic of geopolitical influences on energy security, publishing 66 articles, and as can be seen from Fig. 7, *Resource Policy* shows a sharp increase in the number of articles published after 2022, possibly due to the increased global energy risks resulting from the Russia-Ukraine conflict, which has become a popular topic of choice for the journal. This is followed by *Energy Policy* (33 articles), *Energy Economics* (27 articles), *Energy Research & Social Science* (17 articles), and *Energy* (16 articles). Among the top 5 journals, journals in the field of energy and resources receive more attention than other fields. In addition, the co-citation network of journals (Fig. 8) shows the common citation relationships between publications published in different journals, with the thickness of the connecting line indicating the strength of the citation. *Resources Policy* and *Energy Economics* are the journals with the highest strength of connectivity, and articles in these two journals have the highest number of citations, suggesting that the content of articles published in *Resources Policy* and *Energy Economics* are highly similar in terms of research direction.

To further clarify the distribution of core journals in this subject area of geopolitical impact on energy security, the Bradford distribution of core journals was mapped using the Rstudio. Bradford's Law describes the uneven distribution of scientific articles across journals due to differences in closeness between specialized disciplines (Bradford, 1934). Journals can be classified into three categories based on the number of articles published. The ratio of the number of journals in each group is $1 : a : a^2$ (Yang et al., 2016), which indicates that a large number of specialized papers are first concentrated in a few core journals, with some papers appearing in other journals related to the specialty. Bradford's Law has been widely used to study different subject trends. Based on the information provided in the data in Table 7, the journals are categorized into three regions, each of which carries approximately the same number of articles. As can be seen in Fig. 9, the core journals in this subject area are mainly *Resources Policy*, *Energy Policy*, *Energy Economics*, *Energy Research & Social Science*. Journals in the core zone account for 2.96% of all journals and publish 33.33% of the articles in the field. Journals in the relevant journals account for 14.07% of the total number of journals and publish 33.8% of the articles in the field, while journals in the discrete journals account for 82.96% of the total number of journals and publish 32.87% of the articles in the field as shown in Table 8. The four journals, *Resources Policy*, *Energy Policy*, *Energy Economics*, and *Energy Research & Social Science*, are more concerned with geopolitics and energy security. Researchers engaged in this field may therefore consider these journals as a source of knowledge.

Contribution of core literature. We used VOSviewer to map the literature coupling network of geopolitical impact studies on energy security to explore the most influential academic literature in the field, as shown in Fig. 10, where the node size indicates the total number of citations to the article and the connecting lines indicate the coupling relationships. Concurrently, the academic literature that has been cited the most is highlighted, and the detailed information of the top 10 most cited articles is listed in Table 9, including the title of the article, the first author, the country of affiliation, publication year, the total number of citations, the journal of publication, and the DOI of the literature. As illustrated in it, the literature with the greatest number of citations is Lynne Chester's article *Conceptualizing Energy Security and Making Explicit Its Polysemic Nature*, published in *Energy Policy* in 2010. This article has been cited a total of 310 times since its initial publication, and it is widely recognized within the industry as a highly cited document in this subject area. This article presented an early research explanation of the conceptualization of energy security. It addressed the multifaceted connotations of energy security, the market paradigm, and its multidimensional nature from a theoretical perspective that informed subsequent studies (Chester, 2010). The second most frequently cited article is *Renewable Energy and Geopolitics: A Review* by Roman Vakulchuk, published in 2020. This review article presented a comprehensive analysis of the geopolitical literature related to renewable energy. The study revealed that many publications on renewable energy and geopolitics employed limited research methodologies, failed to delineate geopolitical periods, and lacked in-depth discussions. Furthermore, the analysis indicated that

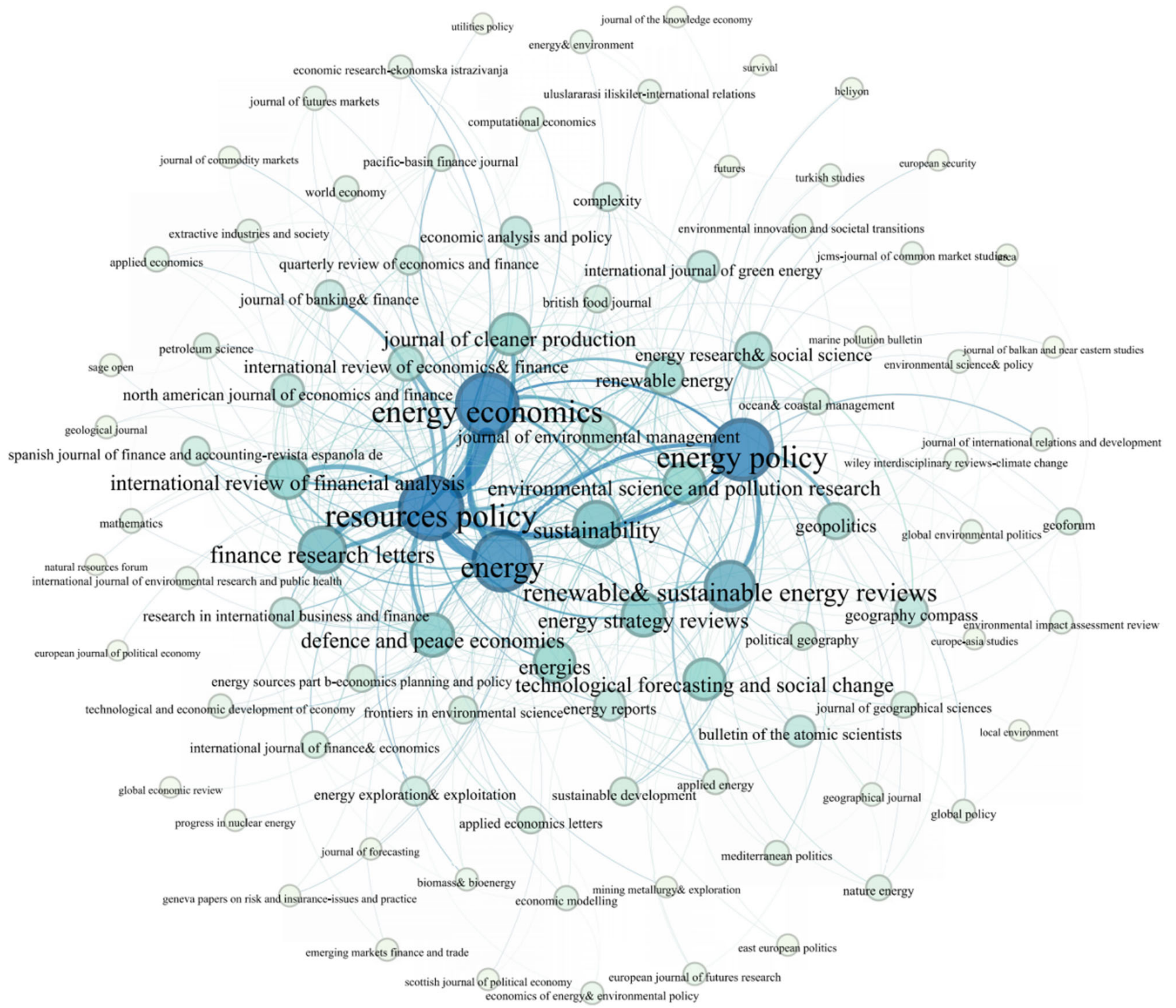

Fig. 8 Journal citation network. This figure depicts the journal citation network, where nodes represent journals, and connecting lines indicate citation relationships between papers published in the journals.

most relevant articles focused on oil-producing countries, while ignoring coal-dependent countries (Vakulchuk et al., 2020). Moreover, it is notable that almost half of the top 10 cited literature originates from China, which serves to corroborate China's research production level in this area.

Thematic distribution

Thematic keywords. Keywords can provide information about the core content of the article (Wang et al., 2024b). The frequency of keyword occurrences over time can reflect research trends in the field of study. We used Rstudio programming techniques to draw keyword heat maps and cumulative keyword heat maps in the research area of geopolitical impact on energy security. As shown in Fig. 11, which demonstrates the top 20 high-frequency keywords in the study of geopolitical impact on energy security. From the keyword heat map and the cumulative keyword heat map, it can be seen that "Natural gas" and "Oil" are the first to appear in the heat map, and both of them have a significant heat in 2006, and the heat lastes for a long time. It shows that the geopolitical impact on energy security is first and foremost reflected in the impact on natural gas and oil and that geopolitics has a significant long-term impact on hydrocarbons. In addition to "natural gas" and "oil" having significant heat in the keyword heat map, other keywords that appear earlier and have significant heat include "Russia" and "China". In addition, in terms of sudden heat, "Climate change" receives huge attention in 2016. "Energy policy", "Energy", "Uncertainty", "Natural gas" and "Oil" have a sudden increase in heat in 2021. The following is an in-depth analysis of the featured keywords.

Natural gas and oil: The co-occurrence mapping of natural gas and oil linked to other keywords is shown in Fig. 12. "Natural gas" co-occurs with several keywords such as "energy security", "consumption", "market", "crude oil", "oil", "policy", "risk", "China", "Russia", "EU", and so on. "Oil" co-occurs with several keywords such as "energy policy", "renewable energy", "market", "natural gas", "vulnerability", "return", "price", "cooperation", "consumption", "China" and "Russia". Natural gas and oil are important energy components and occupy a prominent place in the global energy landscape. Natural gas is a vital source of electricity generation, and natural gas-fired power plants can provide backup and grid stability for intermittent renewable energy sources such as solar and wind power (Baldick, 2014; Mac

Table 7 Statistics on journal literature publication information.

No. of journals	No. of articles	Cumulative number of journals	Cumulative number of articles	No. of journals*Cumulative number of articles	Ln (Cumulative number of journals)
1	66	1	66	66	0
1	33	2	99	99	0.693147181
1	27	3	126	126	1.098612289
1	17	4	143	143	1.386294361
1	16	5	159	159	1.609437912
1	14	6	173	173	1.791759469
1	13	7	186	186	1.945910149
1	11	8	197	197	2.079441542
2	10	10	207	414	2.302585093
1	9	11	216	216	2.397895273
1	8	12	224	224	2.48490665
3	7	15	231	693	2.708050201
1	6	16	237	237	2.772588722
2	5	18	242	484	2.890371758
2	4	20	246	492	2.995732274
5	3	25	249	1245	3.218875825
25	2	50	251	6275	3.912023005
84	1	134	252	21168	4.8978398

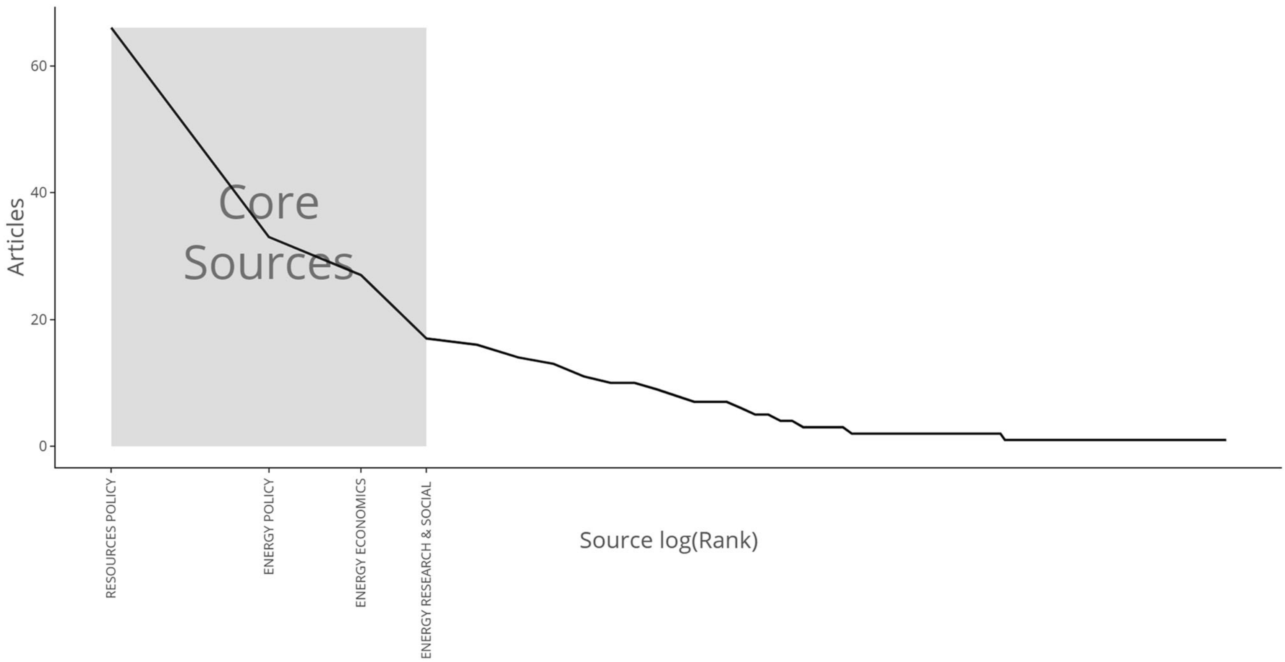

Fig. 9 Core journal distribution. This figure illustrates the distribution of core journals within the field of study. The horizontal axis represents the journal category, the vertical axis represents the number of journal publications, and the shaded area represents the range of core journals.

Kinnon et al., 2018), their ability to increase or decrease rapidly complements the variability of renewable energy production. Natural gas is highly efficient, flexible, and low-emission compared to other fossil fuels, and natural gas produces fewer carbon emissions and less pollution when burned (Safari et al., 2019). At the same time, natural gas is an important source of energy to support industrial production and social life. Oil is a key feedstock for the petrochemical industry (Keim, 2010). It provides raw materials for the production of a wide range of products, including plastics, synthetic rubber, solvents, fertilizers, and chemicals, and is an important driver of global trade and economic activity. The geopolitical impact on energy security is the first thing that prompts global scientists to discuss natural gas and oil, given their wide-ranging and important international status, for geopolitical factors play a crucial role in determining the global distribution of natural gas reserves and oil. Countries with rich hydrocarbon reserves often have important strategic advantages that influence regional political alliances, trade relations (Gu and Wang, 2015). And geopolitical tensions could disrupt oil and gas supplies and affect global oil and gas markets. Armed conflict and political instability in natural gas regions increase the risk of gas supply disruptions and hinder the construction of projects such as gas pipelines.

Russia and China: The connection between Russia and China in the keyword co-occurrence diagram is shown in Fig. 13. Russia has co-occurring relationships with the keywords “energy security”, “gas”, “oil”, “cooperation”, “Ukraine”, “Europe”,

Table 8 Partitioned list of journals.

Category level	No. of journals	% of total journals	No. of publications	% of total publications	Average number of publications per journal
Core journals	4	2.96	143	33.33	35.75
Relevant journals	19	14.07	145	33.80	7.63
Discrete journals	112	82.96	141	32.87	1.26

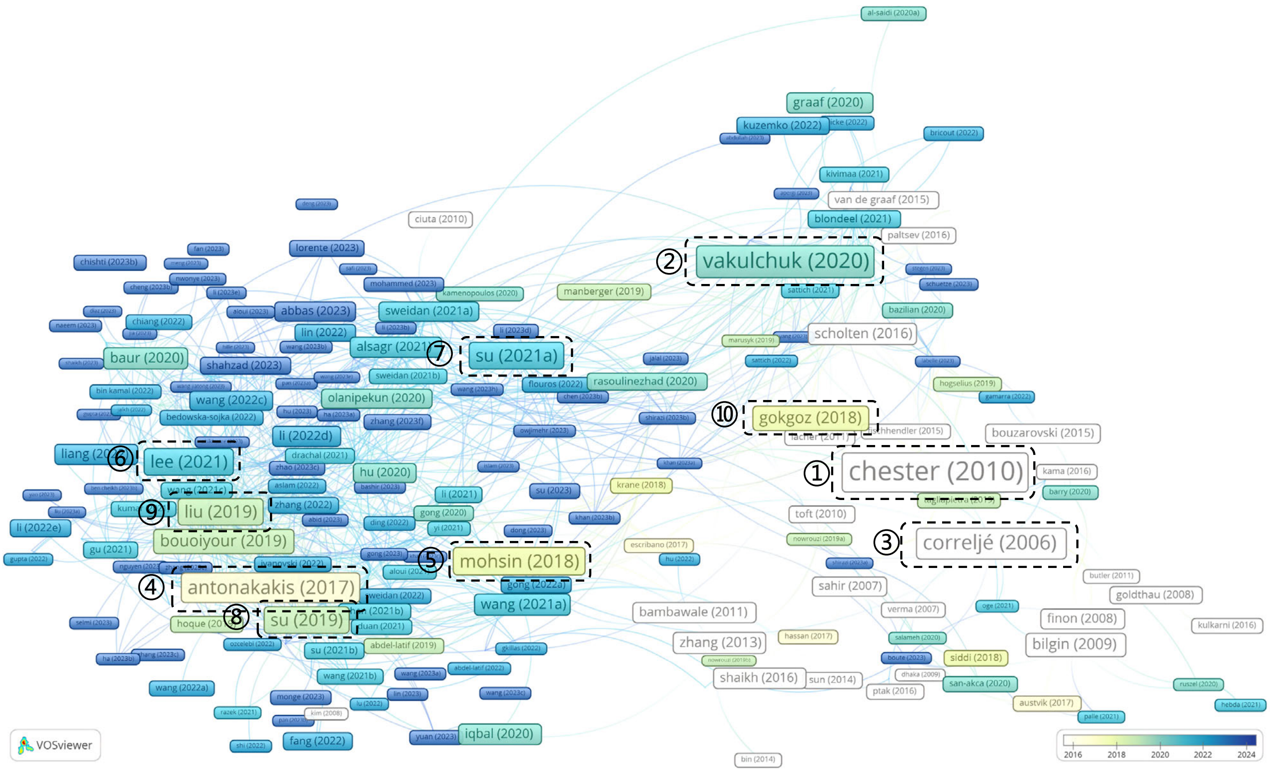

Fig. 10 Literature coupling. This figure represents the literature coupling network, the nodes represent the literature, the node size represents the number of citations, the node connecting lines represent the coupling relationship of the literature, and the node color represents the time distribution.

"renewable energy", "China", "policy". In the co-occurrence mapping of the keyword China, there are co-occurrence relationships for several keywords such as "economic growth", "energy security", "energy transition", "oil price", "cooperation", "return", "demand", and "consumption". Russia has the world's largest natural gas reserves and is one of the largest producers of crude oil, as well as being the world's largest producer and exporter of natural gas (Karacan et al., 2021). In view of the geographical advantages, a number of European countries have formed close energy cooperation with Russia, and the rich energy reserves have become an important tool for Russia's strategic negotiations and energy diplomacy (Bilgin, 2009). Russia is located in a geopolitical risk zone, with armed conflict with Ukraine in 2022 having a huge impact on Russian and global energy markets (Rokicki et al., 2023). Several European countries have restricted Russian energy imports, leading to an energy supply crisis in Europe (Kuzemko et al., 2022). China is the world's largest energy consumer, and the diversification of China's energy mix has made it more concerned about global energy security conditions (Boute, 2019). This is because China's energy demand is fueled by rapid economic growth and accelerated industrialization. Whereas China is heavily dependent on energy imports, the impact of regional conflicts and political tensions on global energy supplies could also affect China's energy import trade. China actively engages in energy cooperation with countries in Central Asia (Zhou et al., 2020) and Africa (Bradshaw, 2009), putting forward the "Belt and Road" initiative, and significant investment in global energy infrastructure was done to increase China's influence in major energy-producing regions, ensure access to key resources and enhance the country's energy security (Duan and Duan, 2023).

Climate change: As shown in Fig. 14, climate change is closely related to the keywords "environment", "energy security", "energy transition", "carbon emissions", "renewable energy", and "cooperation". Climate change has been an important global issue, and its involvement in the discussion of geopolitical influences on energy security is notable. On the one hand, geopolitical factors have led to changes in global energy consumption patterns, and the deterioration of inter-State relations could re-exacerbate dependence on fossil fuels such as coal, oil, and gas. The "Escalation effects" of geopolitical risks reduce renewable energy consumption and lead to higher carbon emissions (Anser et al., 2021). Geopolitical decisions related to the development of energy infrastructure may affect the integration of renewable energy into national or regional energy systems, slowing down clean energy deployment plans and increasing global greenhouse gas emissions. On the other hand, favorable geopolitical policies and international cooperation can drive investment in clean energy

Table 9 Information on the top 10 most cited literature.

Rank	Document title	Author	Country	Year	Citations	Publication source	DOI
1	Conceptualizing energy security and making explicit its polysemic nature	Lynne Chester	Australia	2010	310	Energy Policy	https://doi.org/10.1016/j.enpol.2009.10.039
2	Renewable energy and geopolitics: A review	Roman Vakulchuk	Norway	2020	226	Renewable and Sustainable Energy Reviews	https://doi.org/10.1016/j.rser.2019.109547
3	Energy supply security and geopolitics: A European perspective	Aad Correljé	Netherlands	2006	204	Energy Policy	https://doi.org/10.1016/j.enpol.2005.11.008
4	Geopolitical risks and the oil-stock nexus over 1899–2016	Nikolaos Antonakakis	Australia	2017	180	Finance Research Letters	https://doi.org/10.1016/j.frl.2017.07.017
5	Assessing oil supply security in South Asia	M. Mohsin	China	2018	160	Energy	https://doi.org/10.1016/j.energy.2018.04.116
6	Oil price shocks, geopolitical risks, and green bond market dynamics	Lee, Chi-Chuan	China	2021	146	The North American Journal of Economics and Finance	https://doi.org/10.1016/j.najef.2020.101309
7	Does renewable energy redefine geopolitical risks?	Su, Chi-Wei	China	2021	142	Energy Policy	https://doi.org/10.1016/j.enpol.2021.112566
8	Does geopolitical risk strengthen or depress oil prices and financial liquidity? Evidence from Saudi Arabia	Su, Chi-Wei	China	2019	139	Energy	https://doi.org/10.1016/j.energy.2019.116003
9	Geopolitical risk and oil volatility: A new insight	Liu Jing	China	2019	138	Energy Economics	https://doi.org/10.1016/j.eneco.2019.104548
10	Energy security and renewable energy efficiency in the EU	Fazıl Gökgöz	Turkey	2018	127	Renewable and Sustainable Energy Reviews	https://doi.org/10.1016/j.rser.2018.07.046

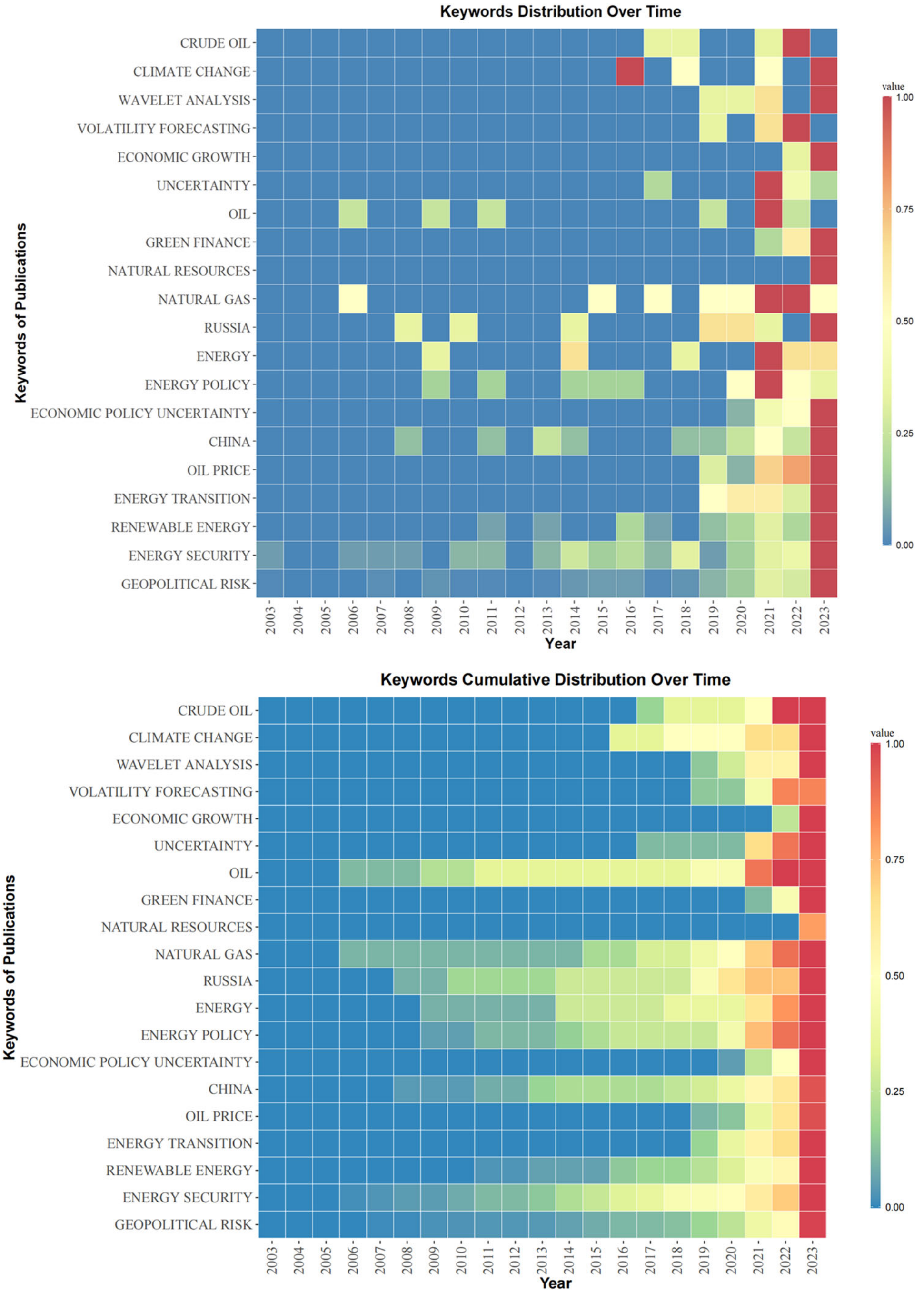

Fig. 11 High-frequency keyword distribution over time and high-frequency keyword cumulative distribution over time. This figure depicts the distribution of keyword frequency and cumulative keyword frequency. The horizontal axis represents the year, the vertical axis represents the keyword category, and the color represents the heat value of the keyword.

technologies and increase opportunities for international R&D cooperation. In conclusion, the implications for climate change under the geopolitical discussion of energy security are complex.

Energy policy and uncertainty: As shown in Fig. 15, energy policy is closely related to the keywords "renewable energy", "price", "oil", "climate change", and "country". In the keyword co-occurrence mapping of "uncertainty", the terms "market," "price," "return," and "economic growth" appear more frequently. Energy policy and uncertainty are key themes influencing the discussion of geopolitical implications for energy security. Government intervention is an important response to energy security issues, and governments around the world develop energy policies as a strategic framework to address the complex interplay of domestic and international factors that seek to enhance energy security and reduce uncertainty in the energy sector (Youngs, 2009). The formulation of energy policy is influenced by factors such as national energy structure and energy consumption (Li et al. 2024). Uncertainty about geopolitical risks also affects national energy policies, and it is important for national policymakers to combine measures to address geopolitical risks with the maintenance of national energy security and to reduce the vulnerability of global energy prices, energy trade, and energy supply to geopolitical risks. Uncertainty in the geopolitical landscape

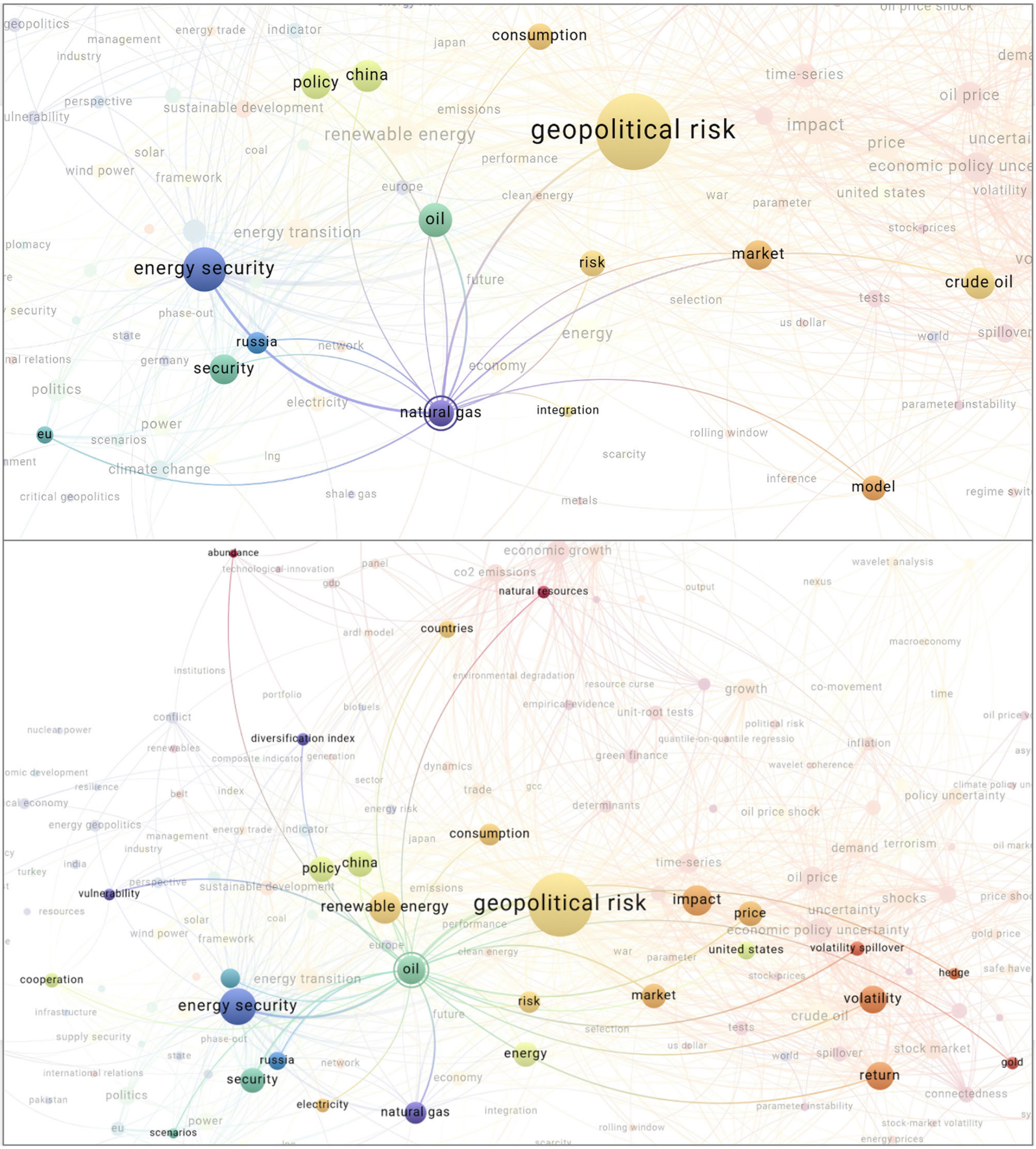

Fig. 12 Natural gas and oil keyword co-occurrence. This figure shows the co-occurrence network for the keywords "natural gas" and "oil", where different nodes represent different keywords and the lines between the keywords represent co-occurrence relationships.

poses a challenge to energy policymakers. Sudden geopolitical events, changes in international relations, or changes in the dynamics of energy markets can threaten energy security, and the development of effective energy policies has become an important tool for addressing geopolitical threats to energy security.

Thematic evolution path. This section mapped the timeline of keyword co-occurrence from the perspective of the temporal evolution of keyword co-occurrence. As shown in Fig. 16, the transition from cold to warm indicates the time from far to near, and the average occurrence time of keywords can be identified by the time color band in the graph. The research phases can be categorized into three distinct phases according to the average year in which the keywords appeared. The average year of emergence of the first stage is 2018–2020, with a focus on the energy sector, which means objects that geopolitics may threaten. The main objects of energy security risks that can be extracted from typical words are "natural gas", "oil", "power", "hydropower", "nuclear power", "fossil fuels", "energy trade", and they form the core of the global energy infrastructure. The identified energy security risks are multifaceted, encompassing not only traditional concerns related to fossil fuels but also reaching into the complex dynamics of the "energy trade".

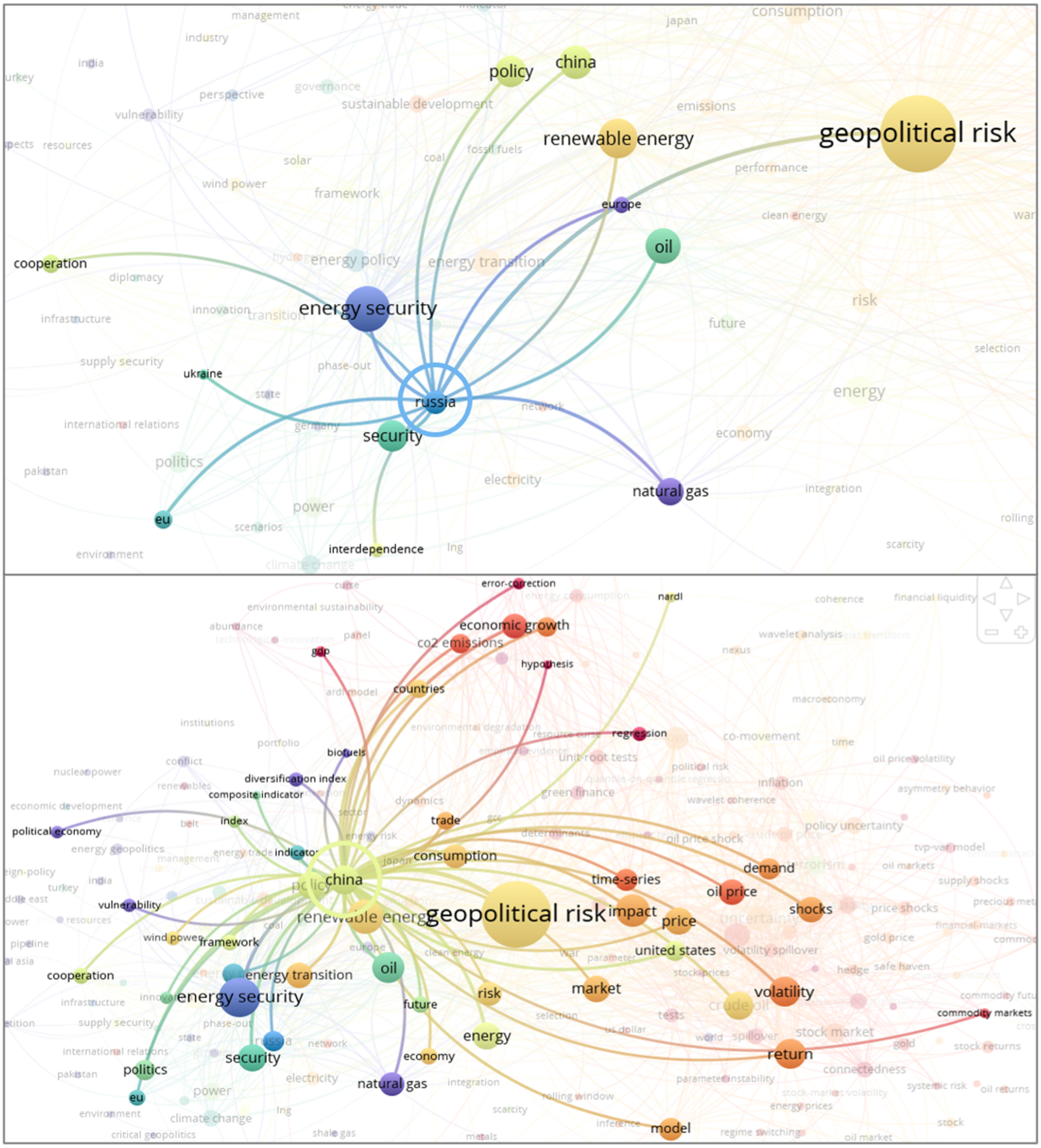

Fig. 13 Russia and China keyword co-occurrence. This figure shows the co-occurrence network for the keywords "Russia" and "China", where different nodes represent different keywords and the lines between the keywords represent co-occurrence relationships.

The interconnected nature of energy resources and their global distribution necessitate a thorough review of trade relationships to assess potential vulnerabilities in energy supply chains. In the geopolitical area, certain countries play a pivotal role, directly affecting or being affected by developments in the energy sector, "China", "Russia", "EU", "United States", "India", "Germany", "Japan", "Turkey", "Central Asia", "Middle East", "Ukraine", "Pakistan", "Poland" are in the spotlight at this stage. Each of these countries faces a unique set of challenges and opportunities in terms of energy security. As mentioned previously, China is a rapidly growing consumer and producer of energy, influencing the global energy market (Odgaard and Delman, 2014). Russia is rich in energy reserves and plays an important role in regional and global energy dynamics. The EU, as a collective entity, plays a central role in the development of energy policies and in promoting cooperation among its member States. India's economy is booming and it seeks to ensure a stable and continuous supply of energy to support its growth trajectory (Kumar and Majid, 2020). Germany, Japan, and Turkey represent industrialized countries with special energy needs and dependencies (Cherp et al., 2017; Kilickaplan et al., 2017). A comprehensive look at countries and regions provides a comprehensive understanding of the interconnected network of energy security issues, including supplier and consumer countries in the global energy landscape. As the research continues, it aims to unravel the intricate relationships, dependencies, and potential hotspots that will shape the future of global energy security.

The average year of occurrence of the second stage is 2020–2022, which is a light warm color on the clustered time plot. During this period, the keywords "geopolitical risk", "renewable energy", "energy transition", "crude oil", "price", "crude oil price", "uncertainty", "return", "demand", "policy uncertainty", "growth", "oil price shocks", "volatility", "price volatility", "markets", "gold price", "stock market" are found to be more frequent. Popular keywords provide a comprehensive overview of key themes and concerns in the energy industry and related markets. The emergence of the term "geopolitical risk" as a focal point indicates an acute awareness of

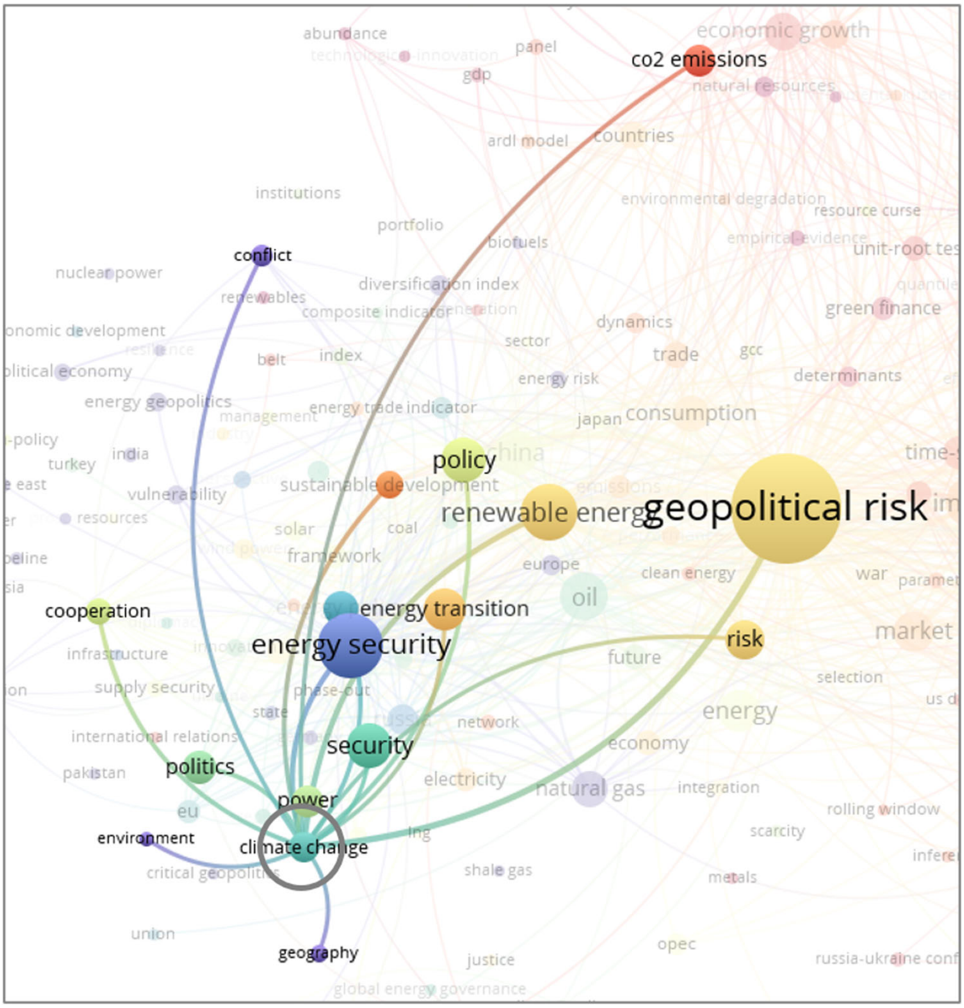

Fig. 14 Climate change keyword co-occurrence. This figure shows the co-occurrence network for the keywords "Climate change", where different nodes represent different keywords and the lines between the keywords represent co-occurrence relationships.

the impact of geopolitical events on energy markets and the wider global economy, as well as a heightened sensitivity to geopolitical tensions, conflicts, and geopolitical strategies that could disrupt energy supplies and markets. "Renewable energy" and "energy transition" continue to feature prominently, highlighting the growing emphasis on sustainable and clean energy. This period has been characterized by growing interest and discussion around the global shift to renewable energy, reflecting a concerted effort to address environmental concerns and reduce dependence on traditional fossil fuels. The constant references to "crude oil", "price" and "crude oil price", together with terms such as "oil price shocks", "volatility", "price fluctuations", "market", "gold price" and "stock market", highlight the energy industry's continued interest in and scrutiny of the intricate relationship between geopolitical risks and global energy markets. Conflicts, political tensions, or disruptions in the oil supply chain in the world's major oil-producing regions could lead to unpredictable and dramatic fluctuations in oil prices. Such sharp fluctuations create uncertainty for both producers and consumers, affecting investment decisions and market dynamics (Mei et al., 2020). In conclusion, this stage of research focuses on the fluctuations of geopolitics in the energy economy market and the financial market, and it is gradually recognized that geopolitics produces dramatic fluctuations in the energy economy market, while the sensitivity of the crude oil price, oil price to geopolitical risks promotes the exploration of measures to resist the geopolitical risks.

The average year of occurrence of the third stage is 2022–2023, which appears in red on the clustered time plot. "GDP", "financial development", "natural resources", "green finance", "determinants", "empirical analysis", "utility testing", "regression analysis", "impulse response analysis", "time series", "wavelet correlation", and other keywords frequently appear. It is worth noting that the interconnection between the financial system and the energy market has received extensive attention from researchers and scholars in the context of the geopolitical impact on energy security, as indicated by keywords such as "GDP", "financial development" and "green finance". The keywords "determinants," "empirical analysis," "utility testing," "regression analysis," "impulse response analysis," "time series," and "wavelet correlation" collectively indicate a methodological shift toward rigorous quantitative analysis at this stage. Researchers seem to have employed advanced statistical tools and econometric techniques to explore the determinants and effects of various factors on energy-related phenomena. The methodological shift suggests that the field is moving toward evidence-based policymaking and a desire to build a solid empirical foundation. The diversity of keywords in this phase implies a multidimensional exploration, integrating economic, financial, and environmental factors, in addition to multiple keywords on research methodology suggesting that research is moving towards more advanced analytical tools and empirical frameworks.

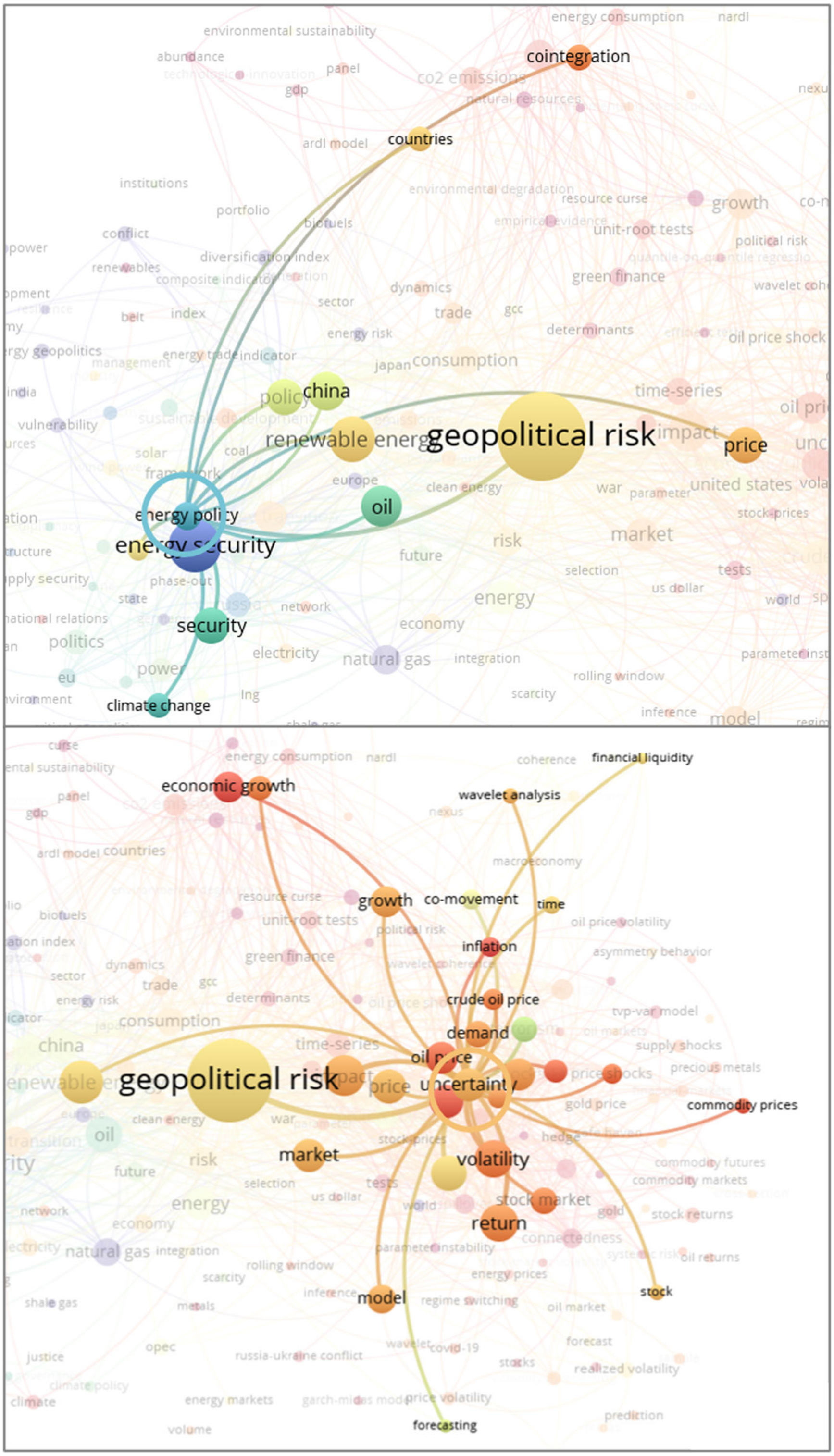

Fig. 15 Energy policy and uncertainty keyword co-occurrence. This figure shows the co-occurrence network for the keywords “Energy policy” and “Uncertainty”, where different nodes represent different keywords and the lines between the keywords represent co-occurrence relationships.

Thematic clustering. Keyword clustering analysis is able to explain the main hotspots in the research field, which was mapped by VOSviewer and Scimago. As shown in Fig. 17, hotspot clusters are distributed in a two-dimensional rectangular coordinate system, and different colors indicate different clusters. The distribution of colors and the legend in Fig. 17 show that the main hotspots in this research area are distributed in six clusters. We obtained cluster labels from the keywords contained in the clusters and discussed with experts to determine the keyword labels that best summarize the nature of the clusters and labeled them in Fig. 17. The size of a clustering cluster is determined by the number of keywords contained in the cluster. The cluster with the largest number of keywords is the green cluster, which focuses on keywords such as “fossil energy”, “clean energy”, “renewable energy” and “energy transition”, it is therefore reasonable to name the green cluster “energy transition”. And then the purple cluster, which is identified through keyword analysis as being closely

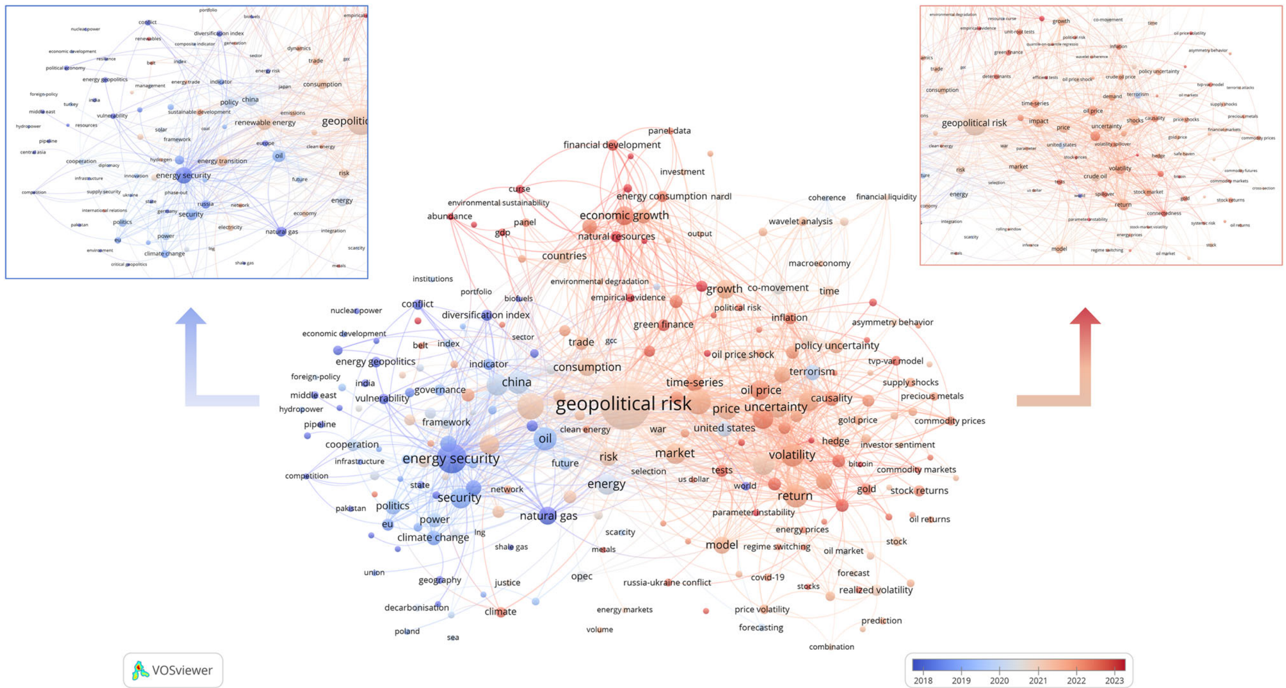

Fig. 16 Keyword co-occurrence timeline view. This figure depicts the temporal evolution of keyword co-occurrences, with colors ranging from cool to warm to indicate time from far to near.

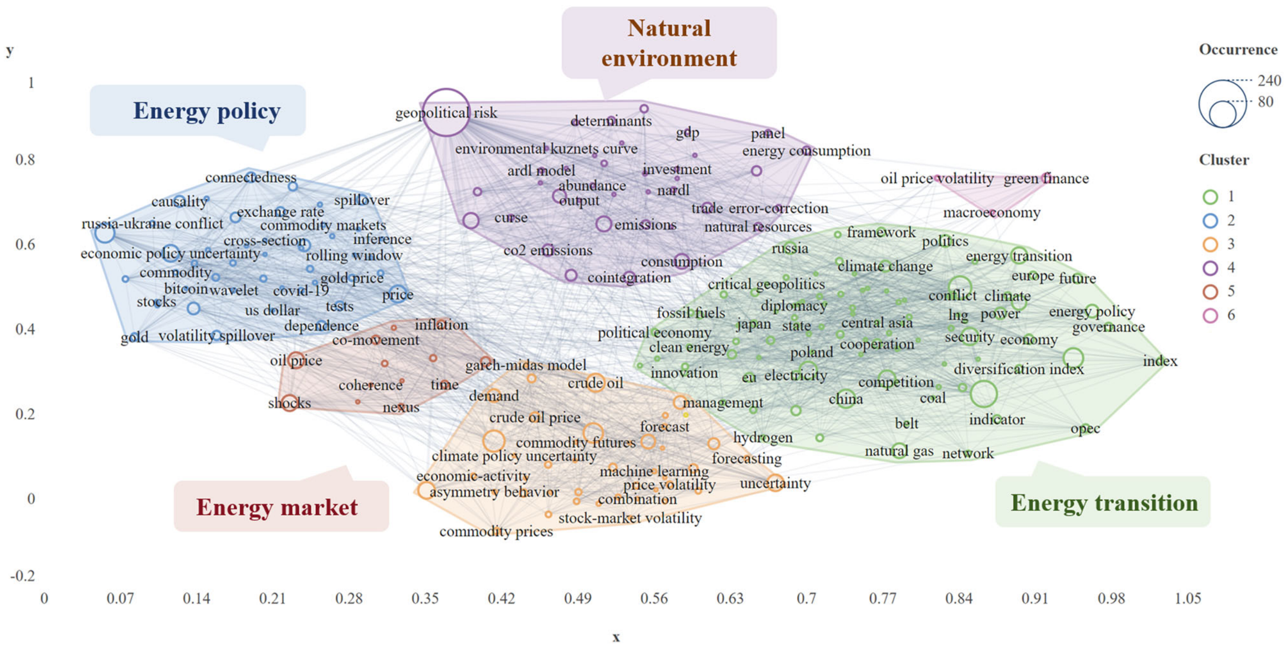

Fig. 17 Thematic clustering. This figure illustrates keyword clustering, wherein nodes represent keywords and different nodes are colored to indicate distinct clusters. The horizontal and vertical axes represent the relative positions of the nodes.

related to the natural environment, and is therefore identified as being labeled "natural environment". Similarly, based on the keyword categories, the blue cluster is labeled "energy policy", and the red and pink clusters, which cover a sparse number of keywords and tend to be similar in nature to the orange clusters, are combined and labeled "energy market". It is worth noting that the horizontal and vertical axes in the 2D cartesian coordinate system have no obvious data meaning, but merely indicate the relative positions of the keywords and their clusters in the 2D space. Subsequently, our study further explored for the identified keyword clusters.

Green cluster: energy transition: Energy transition refers to a change in the way energy is utilized, a reduction in the share of fossil energy in the energy mix, and a transition from traditional fossil energy consumption to clean energy consumption (Rasoulinezhad et al., 2020). Geopolitical risk works both ways for energy transition, with major changes in international energy markets under the Russia–Ukraine conflict. European countries, opposed to Russia's military conflict over Ukraine and determined to reduce energy trade with Russia, have resumed coal- and oil-fired power generation amid gas shortages (Wang et al., 2023), higher geopolitical risk also increases the cost of renewable energy deployment (Shirazi et al., 2023), slows down the energy transition and inhibits the transition to renewable energy. Meanwhile, "high-risk" countries at geopolitical centers may face obstacles in seeking foreign investment, inhibiting the development of renewable energy infrastructure (Fischhendler et al., 2021). On an optimistic note, studies have demonstrated the positive contribution of geopolitical risk to the development of renewable energy, with high geopolitical risk spurring countries to consume more renewable energy (Sweidan, 2021), which could be an important tool to facilitate the clean energy transition (Liu et al., 2023). The complex relationship between geopolitical risk and renewable energy has been subjected to multiple argumentative studies, and thus energy transition is one of the important research directions for researchers and scholars in various countries in the context of geopolitical risk affecting energy security.

Purple cluster: natural environment: The three themes of geopolitical risk, energy security, and climate change have become popular topics for researchers and scholars around the world. Geopolitical tensions not only bring political and economic uncertainty but also harm the natural environment (Acheampong et al., 2023). The direct impact of geopolitical risk on the environment is manifested in the control of and access to valuable natural resources, such as oil, gas, minerals, and water, competition for which can lead to overexploitation, environmental degradation, and ecosystem destruction (Li et al., 2023). International conflicts and armed struggles also have a greater impact on the surrounding environment, and conflicts can lead to increased air pollution and destruction of green facilities in the region, and the production and manufacture of military equipment can increase atmospheric carbon dioxide (Ullah et al., 2020). Furthermore, geopolitical risks act on the natural environment by affecting the consumption structure of the energy sector. The previous analysis showed that the process of energy transition was negatively affected by geopolitical risks, the decline in the consumption of renewable energy sources, and the reduction of clean energy infrastructure were not conducive to the suppression of carbon emissions. In addition, unfriendly relations between countries can hamper global cooperation in addressing climate change and environmental issues, and prolonged hostilities can impede the conclusion of bilateral or multivariate agreements, which in turn affects sustainable development (Zhao et al., 2021).

Red, pink, and orange cluster: energy market: Geopolitical risks have historically played an important role in influencing global energy prices. One study summarized three channels through which geopolitical risk affected energy prices: the threat of conflict acting on energy conversion resulting in lower oil prices, the impact on energy prices of rising negative investor sentiment due to the threat of conflict, and the role of geopolitical uncertainty on energy supply and demand (Li et al., 2020). Additionally, geopolitical tensions and conflicts in major oil- and gas-producing regions could disrupt the production and transportation of energy resources. For example, conflicts in the Middle East involving major oil-producing countries such as Iraq or Saudi Arabia had the potential to result in supply disruptions and subsequent increases in oil prices (Cunado et al., 2019; Su et al., 2019). Then, geopolitical events have affected national foreign trade policies, leading to the imposition of sanctions or embargoes on certain countries, restricting their ability to export or import energy resources, and reducing the global supply of oil and natural gas, resulting in higher prices. Thus, the complex relationship between geopolitical risks and global energy markets has led to a strong interest in this direction among researchers and scholars in various countries.

Blue cluster: energy policy: As Governments grapple with the dual challenge of meeting growing energy demand and addressing climate issues, the energy policy landscape has changed significantly and is often influenced by geopolitical risks. Energy policy is an integrated strategic framework for managing the production, consumption, and sustainability of a country's energy resources and plays an important role in economic development, national security, and environmental stability (Chen, 2011). The multidimensional objectives of energy policy underscore its centrality to national interests: ensuring reliable and affordable energy supplies, promoting economic growth, reducing environmental impacts, and enhancing energy security (Doukas et al., 2008). Energy policy is undergoing transformative changes in the contemporary geopolitical landscape, driven by an intricate interplay of technological advances, environmental imperatives, and geopolitical risks (Wang et al., 2024). The geopolitical landscape brings a layer of complexity to energy policy, as countries must navigate an intricate web of alliances, rivalries, and resource dependencies. Geopolitical risk manifests itself in the energy sector in a variety of ways, including disruptions in the global energy supply chain due to conflicts in major oil-producing regions, and trade disputes affecting energy trade (Golan et al., 2020; Zhang et al., 2023b). In the face of these risks, there is a need for a nuanced energy policy that requires a comprehensive understanding of how global geopolitical dynamics can affect energy markets and, in turn, a country's energy security. Therefore, as the world faces continued geopolitical uncertainty, energy policy will continue to evolve, reflecting the need to balance energy security, economic development, and environmental sustainability in an increasingly interconnected and dynamic global environment.

Conclusions, implications, and limitations

Geopolitics has a profound impact on the energy sector, and the threat in particular is global energy security. Using a systematic literature review and bibliometric analysis, we analyzed more than 400 articles published in the Web of Science core collection qualitatively and quantitatively, and identified the historical development trend, the distribution of research power, the overview of the international collaboration, the research hotspots, and the evolution path of the research. The main findings of this study are as follows:

(1) Researches in geopolitics and energy security is under development, the subject area has moved away from economic factors in the distribution of scientific research to a greater reliance on the global distribution of energy sources. In other words, the distribution of literature output in this subject area no longer follows the trend of distribution between developed and developing countries but is distributed in energy-rich countries or regions, such as oil and gas resources.

(2) The macro-, meso- and micro-networks of scientific collaboration show a more connected group of collaborators, with China as an important research force in the field, and strong links with a number of countries in the Americas, the Middle East and Europe. A total of 27 collaborative groups are generated globally in the institutional collaborative network (ICN). Among them, Qingdao University (China), which has formed the largest collaborative network with a number of institutions at home and abroad, represents the collaborative institutions of the center. Chi-Wei Su is identified as an important co-occurring author in the author collaboration network (ACN), with a large number of collaboration clusters center on him. The K–S test verifies the validity of Lotka's Law for the distribution of authors in this field and the application of Bradford's Law identifies the core journals in this research area as *Resource Policy*, *Energy Policy*, *Energy Economics*, *Energy Research & Social Science*.

(3) The keyword heat map of the thematic analysis shows that the first keywords to be hit in this area are natural gas and oil, and that there is a long-term impact on hydrocarbons, and keywords such as climate change, energy policy, and uncertainty have received sudden attention additionally. The evolutionary path of the thematic analysis shows the three main stages of the development of this research topic, while the keyword clustering shows that the research on this topic focuses on the areas of energy transition, energy markets, energy policy, and the natural environment.

Our research prompts global policymakers to pay further attention to the uncertain risks posed by geopolitics to energy security, and endeavor to promote scientific research collaboration and international goodwill among countries to solve practical problems together. Concurrently, it is imperative to rectify the principal research direction, accelerating the transformation of the country's energy structure, maintaining the stability of the energy market, and formulating rational energy policies, while paying attention to the impact on the natural environment. In addition, our research has certain advantages in terms of identifying overall trends and future directions of a research topic, however, there are still some limitations in data collection, data processing and tool application. First, our data were obtained from the Web of Science core collection, and by manually reading the titles, abstracts, and bodies, we screened the academic papers that best fit the topic for inclusion in the subsequent analysis, but we still failed to immune to omissions. The homogeneity of the database selection may result in the omission of gray literature in the field, as we initially focused on high-quality literature published in high-quality journals. Second, in addition to academic papers, which can represent a country's research priorities, other categories of academic activities such as research projects, conference papers, and books can also reflect research trends to a certain extent, however, our paper data excluded this information, and it is possible for future research to collect and process the results of the different academic categories to enrich the field's research. Finally, the systematic limitations of the bibliometric approach may have produced errors in the results of the statistical and bibliometric analysis of the articles, and future research could further improve the research methodology to reduce systematic errors.

Data availability

The datasets publicly available should be through https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/DYCRUR.

Received: 1 February 2024; Accepted: 22 July 2024;
Published online: 22 August 2024

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Acknowledgements
This work is supported by the "Youth Innovation Team Project" of the Higher Education Institutions under the Shandong Provincial Department of Education (No. 2023RW015), and the National Natural Science Foundation of China (No. 71874203).

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QW: Conceptualization, methodology, software, data curation, writing—original draft preparation, supervision, writing—reviewing and editing. FR: Methodology, software, data curation, investigation writing—original draft, writing-reviewing and editing. RL: Conceptualization, methodology, data curation, investigation writing-original draft, writing—reviewing.

Competing interests
The authors declare no competing interests.

Ethical approval
This article does not contain any studies with human participants performed by any of the authors.

Informed consent
This article does not contain any studies with human participants performed by any of the authors.

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