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Research paper

The knowledge map of energy security

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ABSTRACT

Much efforts have been made in the area of energy security in recent years, but due to its wide scope, it is necessary to review relevant knowledge activities and to analyze the state of knowledge of the field of energy security measurement. The purpose of this article is to present a comprehensive map of knowledge in the field of energy security. For this reason, many documents and articles have been collected during the period 2002–2019 using 7 large and reputable scientific databases as well as 53 different journals, 90% white Q1 quality. There is employed meta-synthesis, scientometrics and network analysis. In the initial survey stage where 1290 articles were found, after analyzing the content using meta-synthesis, 240 scientific articles related to energy security were identified. Then, the following 14 key questions were addressed such as the main conceptual models, processes, and concept structures (concept map). The VOSviewer and Gephi software are also used to explain the conceptual structure (concept map), hot map, co-occurrence map between keywords and their categorization. After Energy Security (and its subsets), the issues of Renewable Energy Security and Energy Supply Security stand in top ranks. The most cited article in this area is the 2006 "Ensuring energy security" article by Yergin on Energy Security. As many as 58 people have published at least two articles, Sovacool with fifteen articles is on the top author with the most published articles in this field. During the evaluation of the articles, 34 conceptual models and 104 quantitative and qualitative methods were found, which illustrate the wide scope of energy security. By examining the coherent vocabulary map in the field of energy security, it can be said that the most important dimensions of energy security include technology, trade, acceptability, productivity, diversity, equity, availability, governance and efficiency.

1. Introduction

Ensuring sovereignty, independence and national security are the main approaches adopted by each country and rely on the availability of natural resources and energy sources, and there is no doubt that sustainable development in the future will still depend on reliable energy supply. As such, in the current context of international development, energy security is a major challenge alongside other global challenges including eradication of poverty, health and education improvement, environmental protection and the development of information and communication technology. From a national development point of view, considering the positive relationship between per capita energy consumption and per capita income level, energy security is a prerequisite for economic development. Lack of planning in the field of energy security can create conditions in which energy does not contribute to economic stability and security, leaving detrimental effects on economic and national security. For this reason, since the beginning of the 21st century, energy security as a strategic policy has been on the agenda of governments and researchers.

Consequently, regarding the broad dimensions and necessity of energy security analysis for the economic development, many scientists and theorists have tried to explain it and provide tools for measuring it for the purpose of designing and implementing policies in energy supply and economic growth. Researchers have also studied the dimensions, indicators, and values of energy security in their respective country because of the context-dependent nature of energy security (Sovacool et al., 2011a; Sovacool and Mukherjee, 2011a; Dike, 2013a).

Studies such as (Vivoda, 2010a) show that the nature of energy security has multidimensional interpretation. Expectedly, the definition of energy security is highly dependent on the context,

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such as specific conditions a country including the level of economic development, risk perception, energy system stability and geopolitical issues.

Among the various tools for analyzing the state of knowledge in the field of energy security, the knowledge map can facilitate policy making in the academic system by outlining the structure of scientific subjects and fields, pursuing the development of texts on specific subjects, and conducting quantitative studies on the advancement of science. Such a study can show the history of science in the field as a guide in future research (Board, 2000).

Therefore, in this research we can understand the process of energy security research using the knowledge mapping tool. We considered several sub-questions to extract and express findings from the articles:

I. What is the most striking trend in this area? (Topic ranking)
II. Are articles more of qualitative or quantitative type? (Research type ranking)
III. What are the seminal works in this area? (Article ranking)
IV. What was the highest number of citations to articles per year? (Top year)
V. Who are the key authors of this area? (Authors rating)
VI. What are the main journals in this area?
VII. What are the main impact factors in the area? (Top journal)
VIII. What is the quality of journals in this area?
IX. What are the top authors, topics and journals each year?
X. What are the leading countries in this area of research? (Country rating)
XI. What are the main conceptual models of this area of research? (Interaction of concepts and their causal relationship)
XII. What are the key processes, procedures, techniques and tools in this area of research?
XIII. What is the conceptual structure (concept map) of this research area?
XIV. What is the summary of research results in this research area?

2. Literature review

2.1. Energy security

Energy security researchers (Von Hippel et al., 2011) believe that with the growing globalization, diversification of energy markets, and exacerbation of transportation problems, past definitions of energy security are less applied, and recently other issues such as climate change, and international, economic and environmental considerations, have gained more momentum in this definition. Daniel (2006) also points out that the traditional conceptualization of energy security is very limited and needs to be expanded to include many dimensions. According to Bohi and Toman (2012), energy security must encompass the three basic concepts of today's world energy supply chain namely price, sustainability and the environment.

New definitions of energy security include the four main dimensions of availability, accessibility, affordability and acceptability (Kruyt et al., 2009a). The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price (Anon, 2021). However, some scholars believe that other dimensions should be added. Von Hippel et al. (2011) believe that there are four other major challenges that must be addressed in the new concept of energy security: (a) the environment, (b) technology, (c) demand-side management and (d) domestic political and cultural-social factors. Vivoda (2010a) also argues that the following three challenges must be addressed in the new concepts of energy security: a) human security, b) international relations and c) politics. The IEA discuses long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply–demand balance (Anon, 2021).

Some studies have provided measurable indicators of energy security. The primary concern in these studies is how countries evaluate their energy security using quantitative indicators. Without a set of standard criteria, it is difficult to determine whether countries are responding properly to emerging energy security challenges related to climate change, increasing dependence on fossil fuels, population growth and economic development. Therefore, it is suggested to create an energy security index to inform policy makers, investors and analysts of the status of energy conditions. For this reason, a number of studies have designed the composite index for energy security. Vivoda (2010a), with a new methodological approach, evaluated energy security in the Asia-Pacific region and provided a systematic tool for calculating the energy security of each region. While describing eleven broad dimensions of the dimensions of energy security, he cites indicators to describe each of these dimensions. In his Asia-Pacific Energy Security Assessment article, Sovacool (Sovacool, 2011a) held Vivoda's article as the point of departure to address energy security challenges and to complementing the dimensions, components, and indicators of energy security. Other researchers, such as Månsson et al. (2014), Ang et al. (2015a) and Song et al. (2019a) have also evaluated energy security. Gasser (2020) analyzed 63 indices to quantify the energy security performance of countries. In particular, their scope, geographical coverage, number of countries analyzed, time frame covered, number of indicators considered, data treatment approach, multivariate analysis, normalization, and other factors were reviewed.

There are many investigations about energy security measurement, but few conducted bibliometric analysis, including co-citation analysis, hot topics, burst detection, and emerging trends. Zhou et al. (2018) adopted a bibliometric method to analyze the above issues and provide a general picture of the research field. By downloading 2845 articles from Web of Science and analyzing the results by CiteSpace, the main findings of the most productive countries, institutions, sources, authors, and interesting research directions in the energy security researches are visually demonstrated.

2.2. Knowledge map

The knowledge map is one of the outputs available to help policymakers. The map shows the static relationship of the system components. It is capable of identifying the sources and paths of knowledge flows along with the limitations and deficiencies of knowledge, and provides managers with the basics of the relevant knowledge, and information on each sub-domain. The knowledge map specifies the number of sub-domains of each field of knowledge and the amount of knowledge available in each sub domain, as well as the relationship and interaction of different sub-domains (Naseri et al., 2012).

In the structural maps of knowledge, the relationships of the different sectors are shown in such a way that conceptually related topics are joined. Here, scientific publications are analyzed with the help of scientometric methods for the purpose of discovering hidden relationships, and then graphically mapped to better understand the results (Naseri et al., 2012).

Balaid et al. (2016) explore the world of knowledge mapping by reviewing and analyzing the current state of research and providing an overview of concepts, benefits, techniques,

Table 1
Research question with parameters.

Parameter	Research question
What, The Study Sample, Time Limit, The Manner of Conducting It	What is the research process in the field of energy security? (2002–2019)

classifications and methodologies, which are precisely reviewed, and their features are highlighted. In addition, we suggested directions for future research.

Many researchers (Dai et al., 2020; Lin et al., 2020; Luo et al., 2019) have used the knowledge map to study their field. Martin, in his article Evolution of Science Policy and Innovation Studies, analyzed recent 50-year-long articles related to this field, exploring the evolution of sub-domain Martin (2012). In his article "Knowledge mapping: The consolidation of the technology management discipline", Pelc describes the property of such maps (Pelc, 2002). Sue and Lee analyzed 556 articles related to the co-occurrence of words and their dynamics in order to show emerging trends in technology foresight knowledge (Lee and Su, 2011).

3. Research methodology

The present research was conducted using a meta-synthesis approach and a scientometric approach and network analysis. In general, meta-synthesis is a type of qualitative study that examines the information and findings extracted from other qualitative studies of relevant subject. Meta-synthesis provides a systematic approach to researchers through a combination of different qualitative researches and explores new and foundational themes and metaphors, thereby enhancing current knowledge and providing a broad and comprehensive view of problems. Due to this relatively new approach, meta-synthesis is not yet widely applied in energy security. Moreover, this approach can be a valuable tool to facilitate the theory-building process through systematic synthesis (Noblit and Hare, 1988). The meta-synthesis approach involves seven steps of setting the research question, selecting eligible and relevant research studies, investigating selected studies, extracting article information, analyzing and combining qualitative findings, and maintaining quality control to discover new and fundamental topics and metaphors. This approach enhances current knowledge and provides a comprehensive view of the issues under investigation. In view of the above steps, it should be noted that meta-synthesis is not only an integrated review of the qualitative literature or analysis of the primary and secondary data of the selected studies, but a tool for the analysis of the findings of these studies (Reddick and Norris, 2013). In fact, this meta-synthesis viewpoint and purpose leads us to answer sub-questions in light of our findings, with reference to the selected articles. As well as, present in the form of significant statistics. These statistics cannot be achieved through merely reading individual articles or reading them in a cluster of articles. The purpose of the meta-synthesis is to develop a theory, summarize, and generalize it with the aim of making qualitative findings more accessible for scientific applications (Paul, 2007).

In the present study, a seven-step, multi-compound approach was used to monitor and select the articles, which were individually studied with their application scrutinized (Paul, 2007).

Step one: Formulating the review question: Various parameters such as What, Who, When, and How are used to set the research question. Table 1 presents the research question along with the parameters.

Step Two. Selecting appropriate research articles: At this stage, eligible studies will be selected for meta-synthesis and the inclusion and exclusion criteria will be determined. At this step, the researcher focuses his or her systematic search on articles published in different journals and finds relevant keywords. This article uses seven prestigious scientific databases, including Elsevier (Sciencedirect), SAGE, Wiley, Taylor and Francis, Springer, Emerald and Inderscience, to search for energy security articles. Advanced Search of all articles was performed which contained the following specialized phrases and keywords related to energy security assessment and evaluation:

- Energy Security Index
- Energy Security Dimension
- Energy Security Definition
- Energy Security Indicators
- Energy Security Assessment
- Assessing Energy Security
- Measuring Energy Security
- Energy Security Evaluate
- Evaluating Energy Security
- Energy Security Measurement
- Energy Import Security
- Energy Export Security
- Security of Energy Exports
- Energy Security Demand
- Energy Security Supply
- Oil Demand Energy
- Oil Import Security
- Oil Export Energy
- Oil Security Index
- Oil Security Indicators
- Gas Demand Security
- Gas Supply Security
- Gas Import Security
- Gas Export Security
- Gas Security Index
- Gas Security Indicators
- Renewable Energy Security Index
- Renewable Energy Security Indicators
- Energy Security Indices

There were 1290 articles in total obtained through advanced search.

In the next step, the researcher first reviewed the search results and eliminated those that do not fit the research question and purpose. Therefore, considering the above keywords, articles whose content was not relevant to the energy security indices were deleted. Finally, articles without authors' names, abstracts, titles, or keywords were removed. Following the above, 740 articles were deleted and 550 remained. These remaining studies entered the next step of the meta-synthesis method.

Step Three: Evaluating research studies: In this step, the researcher must evaluate the methodological quality of the study. The purpose of this step is to remove articles the findings of which cannot be confirmed by the researcher. A tool commonly used to evaluate the quality of early qualitative research studies is the Critical Appraisal Skills Programme (CASP) which helps to identify ten questions to determine the accuracy, validity, and importance of qualitative research studies. These questions focus on the following:

1. Research objectives
2. Method
3. Research design

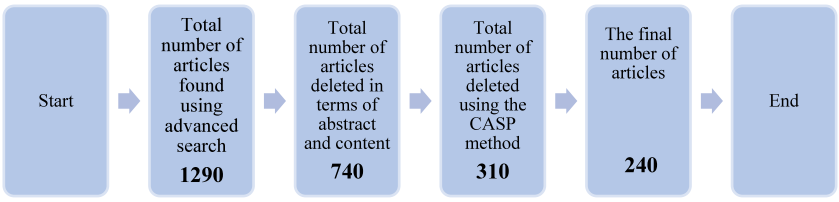

Fig. 1. Summary of search results and article selection.

4. Sampling method
5. Data collection
6. Reflection that involves the relationship between the researcher and the participants.
7. Ethical considerations
8. Accuracy of data analysis
9. Clear expression of findings
10. Research value.

At this point the researcher assigns points to each question and then creates a form. After summing the scores for each article, the researcher will arrive at an evaluation of the results.

Based on the 50-point scale of the Critical Appraisal Skills Programme, the researcher proposed the following scoring system and deleted any article with the score of less than 30. As a result of two evaluation processes, the researcher removed 310 articles out of 550 and eventually 240 articles entered the coding step. In the present study, the review process is summarized in Fig. 1.

Step Four: Extracting article information: Throughout the meta -synthesis and in order to gain insight into the individual contents in which the original and preliminary studies are carried out, the researcher reviewed the selected and finalized articles several times.

In the present study, articles are characterized in terms of: citation (including author's first and last name), publication date, concepts of energy security (as mentioned in each article, and the main purpose of the research), abstract, keywords, country of submission, citation rate, journal name, and key methodological information such as methodology, procedures, and measurement tools.

Step Five: Analyzing and synthesizing qualitative findings: The goal of meta-synthesis is to create a new and integrated interpretation of the findings. It is used to clarify the concepts and patterns, and results in refining existing modes of knowledge and the emergence of established models and theories. Throughout analysis, the researcher investigates themes that have emerged in the meta -synthesis. Sandelowski and Barroso refer to this as a "subject study", in that the researcher identifies themes. Once the themes have been identified, the reviewer forms a classification and puts similar and relevant classifications into the topic that best describes it. Themes provide the basis for creating "explanations and models, theories, or working assumptions" (Sandelowski and Barroso, 2006).

Step Six. Maintaining quality: In the meta- synthesis approach, the researcher considers the following procedures for maintaining quality in his study:

- Providing clear explanations and descriptions of the options available in the research.
- Searching to find relevant articles.
- Applying The quality control methods used in original qualitative research studies.
- In evaluating the quality of the research integration, the researcher uses the CASP tool, "10 Questions That Help You Make Surveys Reasonable".

Step Seven. Presenting findings: At this stage of the meta-synthesis, the findings from the previous steps are presented, as elaborated in the next section.

Reliability of this study was calculated using Kappa coefficient in SPSS software. The information extracted from the six articles, as stated in the sub questions, is obtained from the other researcher, the results are analyzed with the software and the kappa index is obtained. The resulting number is 0.87, which is an acceptable number.

In this research, text mining techniques have been employed such as scientometrics and network analysis to map knowledge. Scientometrics is the application of mathematical and statistical methods to the analysis of metadata related to books and other communication media such as books, reports, theses, articles, and electronic books (Fennell et al., 2008). Initially, 240 selected articles from the meta -synthesis were entered into Rapidminer, VOSviewer and Gephi softwares. After the text mining for one phase and deletion of redundant words, 410 words were created from the analysis of abstracts. We obtained a graph with 2132 edges and with the elimination of words with only one repetition in the whole articles, we reached 1389 edges. Subsequently, a knowledge map in the field of energy security was presented by plotting the graph and grading it with the criteria of betweenness centrality and degree of centrality and deletion of non-semantic words.

4. Answering research questions

I. What is the trend in this area? (Topics ranking)

After reviewing the goals and methodology of articles, the categories of topic (Fig. 2) are discussed in the field of energy security measurement. Summarizing the research results in this area shows that the topic of "energy security" (and its subsets) including "energy security index", "energy security dimension", "energy security definition", "energy security indicators", "energy security assessment", "assessing energy security", "measuring energy security", "energy security evaluate", "evaluating energy security" and "energy security measurement" with the most research interest in this area. After that, the issues of "renewable energy security" and "energy supply security" come in the second and third ranks.

II. Are articles more of qualitative or quantitative type? (Research type ranking)

After reviewing the methodology of the articles, they were divided into three categories: quantitative, qualitative and mixed. The results show (Fig. 3) that 53% of the articles have adopted quantitative methods, 34% qualitative methods and the remaining 13% have a combination of quantitative and qualitative methods (mixed methods).

III. What are the seminal works in this area? (Articles ranking)

To determine the main articles of the journal impact factor indices, the journal quality index and the number of citations to the Google Scholar article were employed. Table 1 shows the top

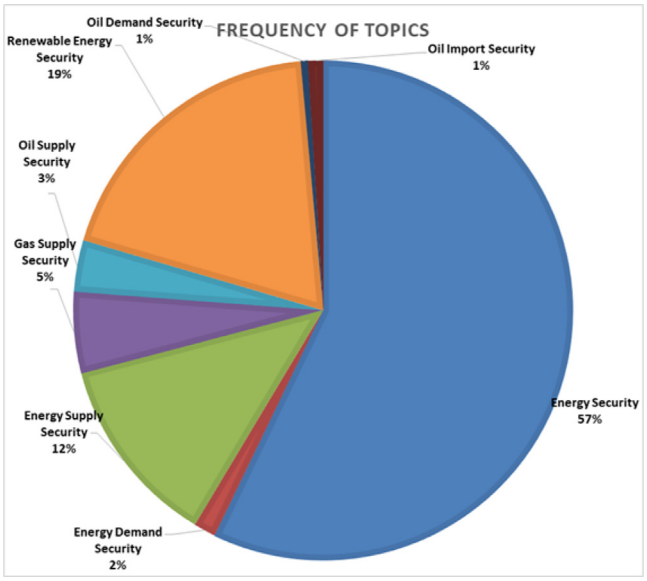

Fig. 2. Ranking of topics.

20 articles in this field according to the number of citations to the article. Table 2 shows main and influential articles in terms of journal impact factor and journal quality, with at least 200 articles cited. According to the two indicators of journal impact factor and journal quality, the 2015 article titled "Energy security: Definitions, dimensions and indexes" by Ang et al. was recognized as the honor article.

IV. What was the highest number of citations to articles each year? (Top year)

According to Google Scholar data, 2006 has been recognized as the top year in this research area with 1290 citations. 2009 and 2012 were next with 672 and 461 citations respectively (see Fig. 4).

V. Who are the main authors of this area? (Authors rating)

This section calculates the total number of articles published by each individual by reviewing 240 articles and the names of their authors. A total of 58 people in this field had at least 2 articles (Table 3), with Sovacool having 15 articles as the highest in this area, and thereby being recognized as the top author. Table 4 also shows the list of top authors with at least 3 articles with H-index and citations. Sovacool earned the H-index = 72 and total number of citations equal to 20,600.

VI. What are the main journals in this area? (Journal rating)

Journals are categorized based on the number of articles in each statistical population, and are classified by frequency as in Fig. 5. Energy Policy was the main journal with the largest number of articles published (33% of articles) in this area. Energy and Applied Energy also ranked second (14%) and third (12%) respectively.

VII. What are the main impact journals in this area? (Top impact factor journals)

As you can see in Fig. 6, the Journal of Renewable and Sustainable Energy Reviews has an impact factor of 10.55 and is recognized as the top journals in the field based on the Impact Factor Index. Applied Energy and Energy Conversion and Management journals were ranked second and third, respectively, with impact coefficients of 8.42 and 7.18, respectively.

VIII. What is the quality of journals in this area?

The quality index is extracted for all journals. As can be seen in Fig. 7, about 90% of the journals were of Q1 quality and the other 5% were of Q2 quality indicating the high quality of the journals used in this study.

IX. What are the top authors, topics and journals each year?

Table 5 lists the top authors, topics, and journals each year. As can be seen, Energy Security and Energy Policy Journal have the highest frequency of all years. Also, 2009, 2013, 2014, 2016 and 2019 have several top authors.

X. What are the leading countries in this area of research? (Countries rating)

This section lists the number of articles published in each country. The criterion for determining each country was whether the article was conducted in that country or not. As can be seen in Fig. 8, China and the United States appear in the forefront of publishing articles in this field. Australia, India, Germany and

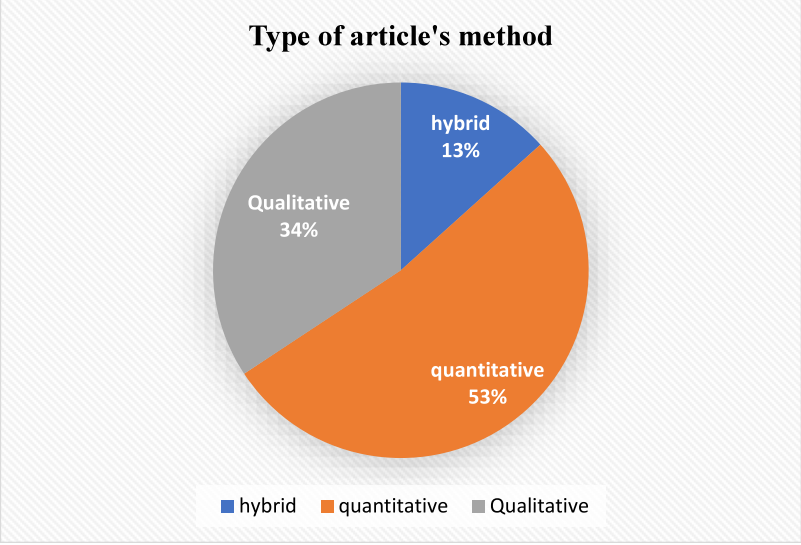

Fig. 3. Ranking of articles by type.

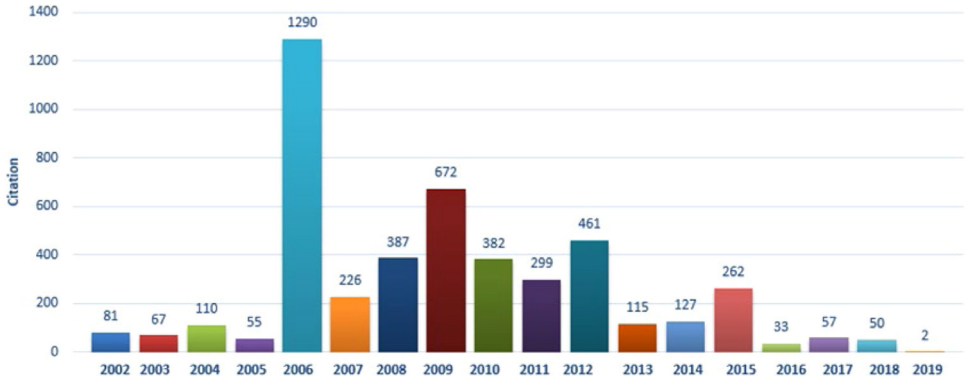

Fig. 4. Maximum number of citations to articles per year (top year).

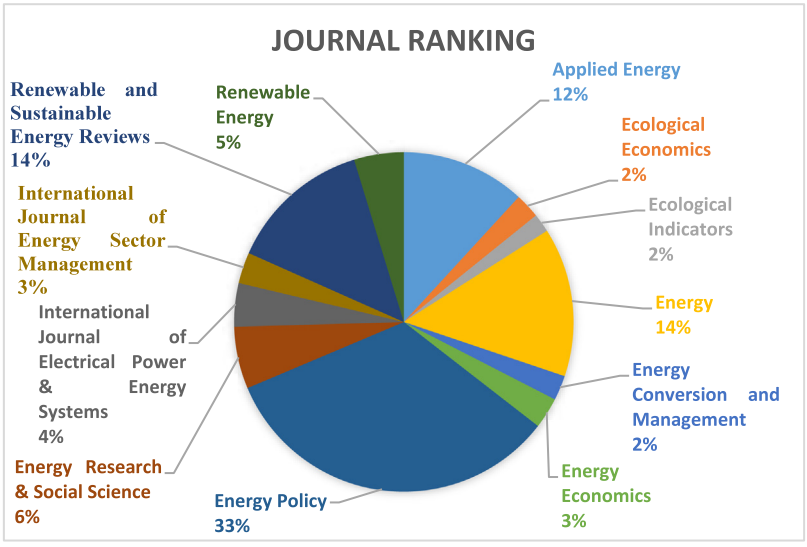

Fig. 5. Journal ranking by frequency of articles.

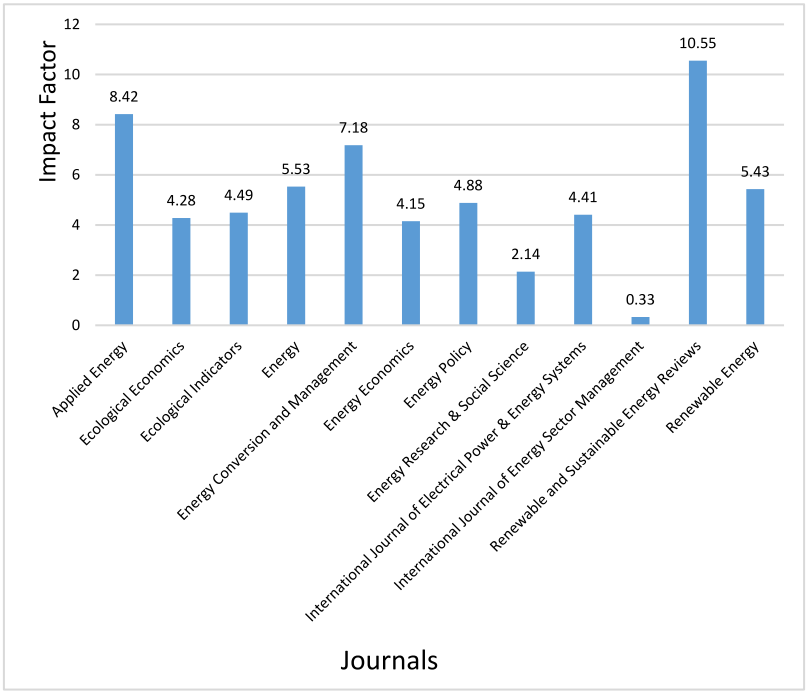

Fig. 6. Top impact journals (2019).

Table 2
Important and influential articles in terms of number of article citations.

NO	Title	Citation	Subject
1	Ensuring energy security	1290	Energy Security
2	Indicators for energy security	672	Energy Security
3	Conceptualizing energy security	461	Energy Security
4	Energy supply security and geopolitics: A European perspective	392	Oil Supply Security
5	Oil vulnerability index of oil-importing countries	387	Oil Supply Security
6	Conceptualising energy security and making explicit its polysemic nature	382	Energy Security
7	Conceptualizing and measuring energy security: A synthesized approach	299	Energy Security
8	Diversity and security in UK electricity generation: The influence of low-carbon objectives	297	Renewable Energy Security
9	Competing dimensions of energy security: an international perspective	287	Energy Security
10	Monitoring changes in economy-wide energy efficiency: from energy–GDP ratio to composite efficiency index	262	Energy security
11	Energy security: Definitions, dimensions and indexes	262	Energy security
12	The three perspectives on energy security: intellectual history, disciplinary roots and the potential for integration	251	Energy Security
13	Measuring the security of external energy supply in the European Union	236	Energy Supply Security
14	Security of energy supply: Comparing scenarios from a European perspective	226	Energy Supply Security
15	Evaluating energy security in the Asia-Pacific region: A novel methodological approach	223	Energy Security
16	Indicators of energy security in industrialised countries	214	Energy Security
17	China's energy security: Perception and reality	201	Energy Security
18	Long-term security of energy supply and climate change	200	Energy Supply Security
19	Energy indicators for tracking sustainability in developing countries	202	Energy security

Table 3
Important and influential articles in terms of article citation.

NO	Author(S)	Total Article	NO	Author(S)	Total Article
1	Sovacool, Benjamin, K	15	30	Iribarren, Diego	2
2	Vivoda, Vlado	5	31	Jewell, Jessica	2
3	Narula, Kapil	4	32	Jun, Eunju	2
4	Augutis, Juozas	4	33	Kumar, S	2
5	Peciulyte, Sigita	4	34	Lu, Weiwei	2
6	Krikštolaitis, Ričardas	4	35	Lucena André, F. P	2
7	Su, Meirong	4	36	Martchamadol, Jutamanee	2
8	Kosai, Shoki	3	37	Baležentis, Tomas	2
9	Cherp, Aleh	3	38	McGillivray, Steven	2
10	Zhang, Mingqi	3	39	Biresselioglu, Mehmet Efe	2
11	Radovanović Mirjana	3	40	Mohsin, M	2
12	Streimikiene, Dalia	3	41	Mukherjee, Ishani	2
13	Filipović, Sanja	3	42	Ng, T. S	2
14	Brown, Marilyn. A	3	43	Pachauri, Shonali	2
15	Choong, W. L	3	44	Prasad, Sameer	2
16	Matsumoto, Ken'ichi	3	45	Reddy, B Sudhakara	2
17	Blahnik, Benjamin	2	46	Ren, Jingzheng	2
18	Bortolamedi, Markus	2	47	Riahi, Keywan	2
19	Andriosopoulos, Kostas	2	48	Su, Hung-Chung	2
20	Chalvatzis, Konstantinos J	2	49	Sudhakara, Reddy. B	2
21	Ang, B. W	2	50	Sun, Xiaolei	2
22	Cox, Emily	2	51	Unesaki, Hironobu	2
23	Fan, Ying	2	52	Wang, Jun	2
24	García-Gusano, Diego	2	53	Wei, Yi-Ming	2
25	Golušin, Vladimir	2	54	Yao, Lixia	2
26	Gracceva Francesco	2	55	Zhou, P	2
27	Hao, Yan	2	56	Ji Qiang	2
28	Hughes, Larry	2	57	Chang, Soon Heung	2
29	Žutautaitė, Inga	2	58	Ioannidis, Alexis	2

Japan also came in second, and Singapore, Spain and Denmark came in third.

XI. What are the main conceptual models of this research area? (Interaction of concepts and their causal relationship)

Among the evaluated articles, 34 articles have the suggested models. In Table 6, we can find relevant articles and models.

XII. What are the key processes, procedures, techniques and tools in this area of research?

Key processes, procedures, techniques and tools were analyzed in this area of research. As evident in Table 7, the 240 articles reviewed used 104 different methods.

XIII. What is the conceptual structure of this research area?

In order to achieve the research goals in knowledge mapping, the keywords and abstracts of 240 identified articles were entered into Rapidminer and VOSviewer software. After entering the data, a co-occurrence matrix of words is formed, and then the output of these software, which includes the co-occurrence matrix, is fed to the Gephi software.

Fig. 9 is the concept structure (concept map) derived from VOSviewer software. The size of each of the circles in this figure represents the number of repetitions of each keyword in the articles under study. The colors of each circle also represent a keyword cluster known as "cluster", which is one of the important outputs of VOSviewer software. Twenty-six categories of

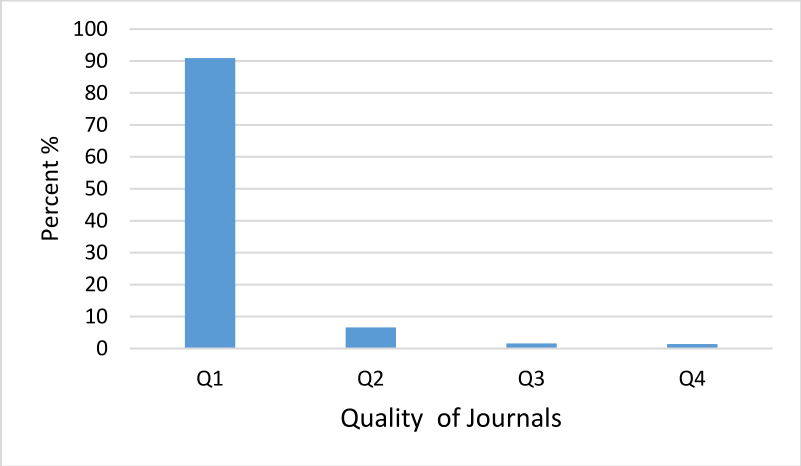

Fig. 7. Quality of journals reviewed in the field of energy security (2019).

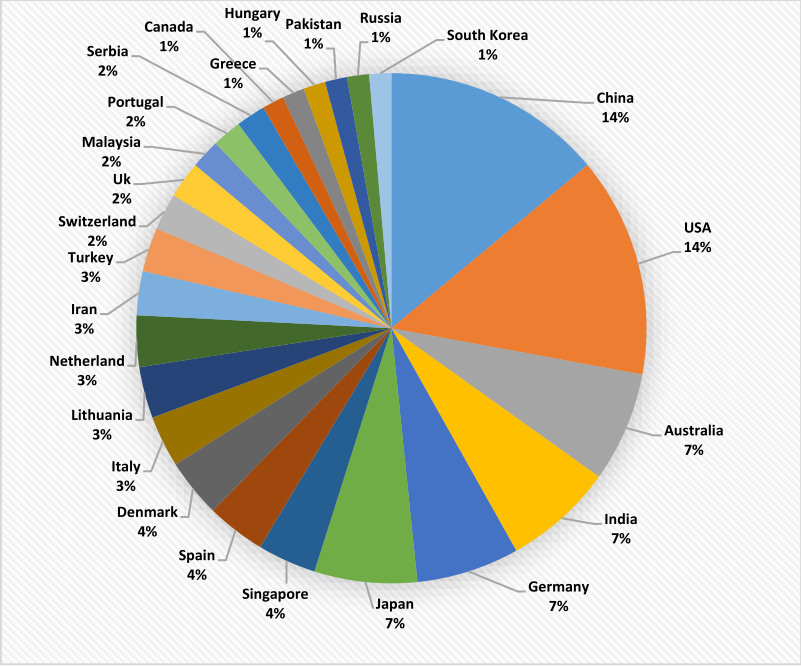

Fig. 8. Ranking of articles by leading countries.

Table 4
Top authors list with at least 3 articles with H-index and references.

No	Author	H-index	Cited by
1	Sovacool, Benjamin, K	72	20 600
2	Vivoda, Vlado	16	1175
3	Narula, Kapil	9	455
4	Augutis, Juozas	7	237
5	Peciulyte, Sigita	7	154
6	Krikštolaitis, Ričardas	8	215
7	Su, Meirong	19	1165
8	Kosai, Shoki	4	47
9	Cherp, Aleh	25	2542
10	Zhang, Mingqi	4	58
11	Radovanović Mirjana	14	726
12	Streimikiene, Dalia	33	4272
13	Filipović, Sanja	10	356
14	Brown, Marilyn. A	36	5688
15	Choong, W. L	28	4037
16	Matsumoto, Ken'Ichi	36	6100

keywords in the field of energy security have been identified in this software classification. The hot map is adopted to determine which topics and keywords are important in each group of the keywords obtained. Fig. 10 shows the hot map obtained from VOSviewer software. As can be seen in Fig. 10, keywords in the yellow area, including "energy security", "energy policy", "climate change", "energy system", "technology" and "trade" are the most important security topics and keywords in the field of energy security.

Due to the specificity of Gephi software in detecting the degree of relevance of keywords together and the ability of this software to determine the betweenness centrality, the output from VOSviewer software is proportional to Gephi software and is given as input to Gephi software. As shown in Fig. 11, the network Gephi software output consists of a set of nodes and lines or links that represent the relationship between them. In these maps, the size of the keywords indicates the frequency of each keyword. The lines indicate the relationship between the two words, and the thickness of the lines indicates the extent of

Table 5
Top authors and topics and journals each year.

NO	Year	The Top Author(s) in Year	The Top Subject(s) in Year	The Top Journal(s) in Year
1	2002	Bielecki, J	Energy Security	The quarterly review of economics and finance
2	2003	Belyi, Andrei	Energy Security/Energy supply security	European Integration
3	2004	Lesbirel, S Hayden	Energy Security	Japanese Journal of Political Science
4	2005	Wright, Philip	Gas Supply Security	Energy Policy
5	2006	Yergin, Daniel	Renewable energy security/ Energy Security	Energy Policy
6	2007	Costantini, Valeria	Energy Security	Energy Policy
7	2008	Gupta, Eshita	Energy Security	Energy Policy
8	2009	Kruyt, Bert; van Vuuren, Detlef P; deVries, Han JM; Groenenberg, Heleen	Energy Security/Energy supply security	Energy Policy
9	2010	Chester, Lynne	Energy Security	Energy Policy
10	2011	Sovacool, Benjamin K	Energy Security	Energy Policy
11	2012	Sovacool, Benjamin K	Energy Security	Energy Policy
12	2013	Blahnik, Benjamin; Sovacool, Benjamin K; Su, Hung-Chung; McGillivray, Steven	Energy Security	Energy Policy
13	2014	Jewell, Jessica; Cherp, Aleh; Riahi, Keywan	Energy Security	Energy Policy
14	2015	Ang, B. W.	Energy Security	Energy
15	2016	Shaikh, Pervez Hameed; Nor, Nursyarizal Bin Mohd; Nallagownden, Perumal; Elamvazuthi, Irraivan; Ibrahim, Taib; Matsumoto, Ken'ichi; Andriosopoulos, Kostas	Energy Security	Energy Research & Social Science
16	2017	Narula, Kapil	Energy Security	Applied Energy/ Energy
17	2018	Radovanović, Mirjana	Energy Security	Energy Policy
18	2019	Ralph, Natalie; Hancock, Linda	Energy Security	Energy

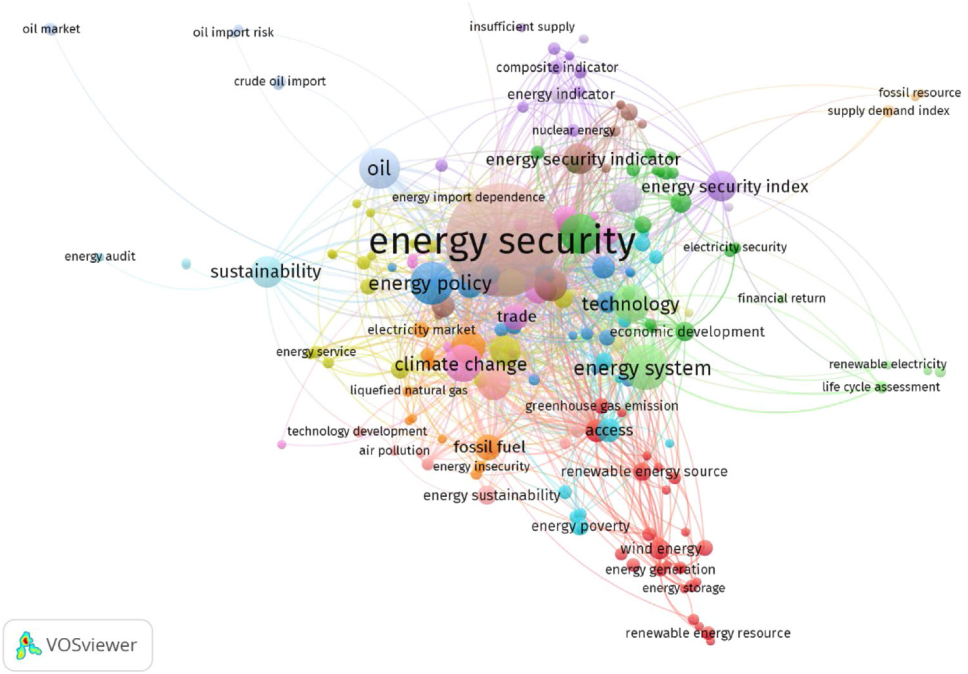

Fig. 9. Concept structure (concept map) derived from VOSviewer software.

the relationship. Words that have a strong association with thick lines and those that have a weak relationship are characterized by narrower lines. In all the articles, the term "energy security" has a high occurrence, with most of the articles focus first on "energy security" (and its subcategory) and then on "energy system", "energy policy", "oil", "energy supply", "climate change", "technology" and "natural gas", respectively.

As a structural feature of the node, the betweenness centrality also indicates the importance of a node in terms of its location on the map and in terms of information transmission over the network. Based on the analysis of the centrality of the betweenness centrality (Fig. 12), it is clear that, the terms "energy security", "energy policy", "technology" and "oil" have the most betweenness centrality, despite many words being listed in the

Table 6
Suggested Models of Articles.

NO	Article	Proposed model
1	Sustainable energy policy indicators: Review and recommendations	A sustainable indicators' framework towards the sustainable energy policy making
2	Construction of evaluation index system of national energy security based on CAS theory and PSR model	Concept framework of PSR model
3	Measuring the security of external energy supply in the European Union	Index designed to evaluate the short-term risks
4	Diversification of oil import sources and energy security: A key strategy or an elusive objective?	Qualitative conceptual framework with which to evaluate the need to diversify their
5	Evaluating energy security in the Asia-Pacific region: A novel methodological approach	Energy security assessment instrument' based on a new and expanded conceptualizations of energy security
6	Long-term energy services security: What is it and how can it be measured and valued?	The concept of energy services security is proposed with a demand-side
7	Energy security policies in EU-25—The expected cost of oil supply disruptions	A framework for analyzing the impact on the expected cost of oil disruption by energy policies in EU-25
8	Conceptualizing and measuring energy security: A synthesized approach	A synthesized, workable framework for analyzing national energy security policies and performance
9	Conceptualizing energy security	we illustrate how the selection of conceptual boundaries along these dimensions determines the outcome.
10	A generic framework for the description and analysis of energy security in an energy system	A framework that attempts to meet this objective by combining the International Energy Agency's definition of energy security with structured systems
11	Mexican energy policy and sustainability indicators	The methodological framework for sustainable energy development proposed by the Economic Commission
12	Assessing Taiwan's energy security under climate change	We construct a static computable general equilibrium model for Taiwan to fulfill our purpose.
13	An international assessment of energy security performance	An energy security index which measures national performance on energy security over time
14	Quantifying the risk to crude oil imports in China: An improved portfolio approach	Establishing an assessment model which has two primary characteristics. First, the model not only uses portfolio theory, Second, the correlation between import prices and global oil prices is analyzed with respect
15	Conceptual proposals for measuring the impact of international regimes on energy security	Conceptual proposals for measuring the impact of international regimes
16	Energy security under de-carbonization scenarios: An assessment framework and evaluation under different technology and policy choices	A framework to evaluate energy security under long-term energy scenarios generated by integrated assessment models
17	Energy security in China: a quantitative analysis and policy implications	A 4-As quantitative evaluation framework
18	Implications of paradigm shift in Japan's electricity security of supply: A multi-dimensional indicator assessment	A baseline and four alternative scenarios were designed
19	Multi-perspective analysis of China's energy supply security	This article constructs a multi-dimensional indicator system for the main risks deriving.
20	Methodology for quantitatively assessing the energy security of Malaysia and other southeast Asian countries	A methodology for quantitatively assessing energy security.
21	The impacts of shale gas supply and climate policies on energy security: The U.S. energy system analysis based on MARKAL model	The framework considers vulnerability as a combination of risks associated with energy trade and resilience reflected in diversity of energy sources and technologies
22	A framework for evaluating Singapore's energy security	A framework with a composite index and three sub-indexes for evaluating Singapore's energy security.
23	MAS-based solution to energy management strategy of distributed generation system	A Multi-Agents System (MAS) based two hierarchical decentralized coordinated control scheme is constructed
24	Materials-based 3D segmentation of unknown objects from dual-energy computed tomography imagery in baggage security screening	Novel technique for the 3D segmentation of unknown objects from cluttered dual-energy Computed Tomography (CT) data obtained in the baggage security-screening domain
25	Intelligent multi-objective control and management for smart energy efficient buildings	Multi-agent control system has been developed in combination with stochastic intelligent optimization
26	Evaluating energy security of resource-poor economies: A modified principle component analysis approach	A novel framework to conceptualize energy security
27	Evaluating the energy security of electricity interdependence: Perspectives from Morocco	A multi-dimensional energy security framework for evaluating electricity integration
28	Integrated energy security assessment	A novel methodology as an integrated framework of different types of analyses and methods of energy security assessment towards the application for energy security level forecasting.
29	A conceptual framework for energy security evaluation of power sources in South Korea	A model that contributes to national energy security by energy source is proposed.
30	Energy governance in the context of energy service security: A qualitative assessment of the electricity system in Bangladesh	Conceptual framework of energy governance with respect to energy service security
31	Dimensions of energy security in Small Island Developing States	A framework for conceptualizing and assessing SIDS energy security which are: import dependency; energy prices; climate change and resilience; governance; infrastructure; equity; and energy efficiency.
32	Assessing national renewable energy competitiveness of the G20: A revised Porter's Diamond Model	An analytical framework for assessing the national renewable energy competitiveness of the G20 members
33	The evolution of the spatial–temporal patterns of global energy security since the 1990s	An energy security evaluation model (ESEM) from three dimensions, energy supply-transport security, safety of energy utilization, and stability of political-socioeconomic environment
34	A SES (sustainable energy security) index for developing countries	An analytical framework for the assessment of sustainable energy security (SES) of an energy system and the methodology for constructing an SES index

Table 7
Tools used.

NO	Method	NO	Method	NO	Method
1	Data Envelopment Analysis (DEA)	36	ERIS	71	Oslo-Potsdam-Solution
2	A composite index approach	37	Factor Analysis	72	PCA
3	A revised Porter's Diamond Model	38	Fuzzy AHP	73	Poisson pseudo-maximum-likelihood (PPML) method
4	An emergy-based index system	39	GA-BPNN	74	Principal component technique
5	AHP	40	GAMS	75	Probabilistic approach
6	Average system interruption duration index (ASIDI)	41	General equilibrium model	76	PROMETHEE
7	Bayesian method	42	Genetic algorithm (GA)	77	PSO-APO algorithm
8	BPNN (Back propagation neural network)	43	Global Malmquist–Luenberger (GML)	78	Renewable energy security index (RESI)
9	Buzan's approach	44	GST-based MCDM approach of COPRAS	79	Risk analysis
10	Capacity factor violation index (CFVI)	45	Herfindahl index	80	Scenario analysis
11	Cluster analysis	46	Herfindahl–Hirschman index	81	Sensitivity analysis
12	Complex adaptive system (CAS)	47	Herfindahl–Hirschman index (HHI)	82	Shannon Wiener index
13	Complex network analysis	48	Energy information administration (EIA)	83	Shannon-Wiener index (SWI)
14	Composite Gas Supply Security Index	49	Hirschman–Herfindahl index (HHI)	84	Shapley index
15	Compromise Programming (CP)	50	Hybrid multi-objective genetic algorithm (HMOGA)	85	simplified coarse-grained model
16	Content analysis	51	Improved entropy method	86	Simulations
17	COPPE-MSB	52	Index grading system	87	Slack-based model (SBM)
18	Correlation analyses	53	Inductive thematic analysis	88	Spearman correlation
19	Descriptive analysis	54	Information gap decision theory (IGDT) method	89	SSDC-MC method
20	MCDM	55	Input–output analysis	90	Stepwise multiple linear regression model
21	Dependence metrics	56	Intelligent water drops (IWD)	91	Stochastic programming
22	Disaggregated index approach	57	Interviews	92	Stochastic Simulation
23	Ecological network analysis	58	Kaya index decomposition approach	93	Subjective and objective weight allocation technique
24	Ecological Network Analysis (ENA)	59	Life cycle assessment	94	Sustainable energy security (SES) index
25	Energy dependency index	60	LMDI index decomposition	95	SWOT analysis method
26	Bottom-up approach	61	Load margin (LM) index	96	System availability index (N-1)
27	Energy indicators for sustainable development (EISD)	62	Long-term energy scenarios	97	System dynamic model
28	Energy Literacy Test	63	Malmquist index	98	System interruption nuclear vulnerability index (SINVI)
29	Energy security and environmental sustainability index (ESESI)	64	Mapping techniques	99	TOPSIS
30	Energy security physical availability index (ESPAI)	65	Measures of systematic and specific risks	100	Two-phase DEA-like model
31	Energy security price index (ESPI)	66	MESSAGE	101	Uncertainty analysis method
32	Energy systems modelling	67	Multi-Objective genetic algorithm (MOGA)	102	Z factor
33	Micro econometric techniques	68	Multiple linear regression models	103	ZEB performance index
34	Min – Max method	69	New-England 39-bus test system	104	OLADE, CEPAL and GTZ's methodology
35	Monte Carlo simulation	70	Oil import vulnerability index (OIVI)	105	———————

text. These thematic categories play an important role in the transmission of information across the network, i.e., they are interdisciplinary approaches to energy security.

5. Summary

XIV. What is the summary of research results in this research area?

In summarizing the research results, the most attractive topics include "Energy Security" such as "energy security index", "energy security dimension", "energy security definition", "energy security indicators", "energy security assessment", "assessing energy security", "measuring energy security", "energy security evaluate", "evaluating energy security" and "energy security measurement". The issues of "Renewable Energy Security" and "Energy Supply Security" come in the second and third ranks.

Fifty-three percent of the articles in this area have quantitative methods, 34% have qualitative methods and the remaining 13% have combinations of quantitative and qualitative methods (mixed methods). The most cited article in this area is "ensuring energy security" article by Yergin, D in 2006 on topic of energy security. Fifty-eight people in this field had at least 2 articles, with Sovacool having 15 articles as the top author.

Energy Policy was the main journal with the largest number of articles published in this area. Over 90% of articles were Q1-quality, with average IF journals averaging 5.16, and Renewable and Sustainable Energy Reviews rated IF = 10.55.

China and the United States had the largest number of articles (30 articles) in this area, and are listed as the leading countries. It can be argued that since these two countries are the world's top economies, they understand the importance of energy security in sustainable development.

In this domain, 34 conceptual models have been presented, the multiplicity of which highlights the importance of energy security. Also, according to the literature review, about 104 quantitative and qualitative methods were found to evaluate the articles, which reflects the breadth of energy security issues.

The conceptual map also shows that the term "energy security" has a high density and co-occurrence in all the articles, with most of the articles focusing primarily on "energy security" and then "energy system", "energy policy", "oil", "energy supply", "climate change", "technology" and "natural gas".

6. Conclusion

Several attempts have been made in the energy security field in recent years, though reviewing the relevant research and analyzing the state of knowledge within this field is necessary due

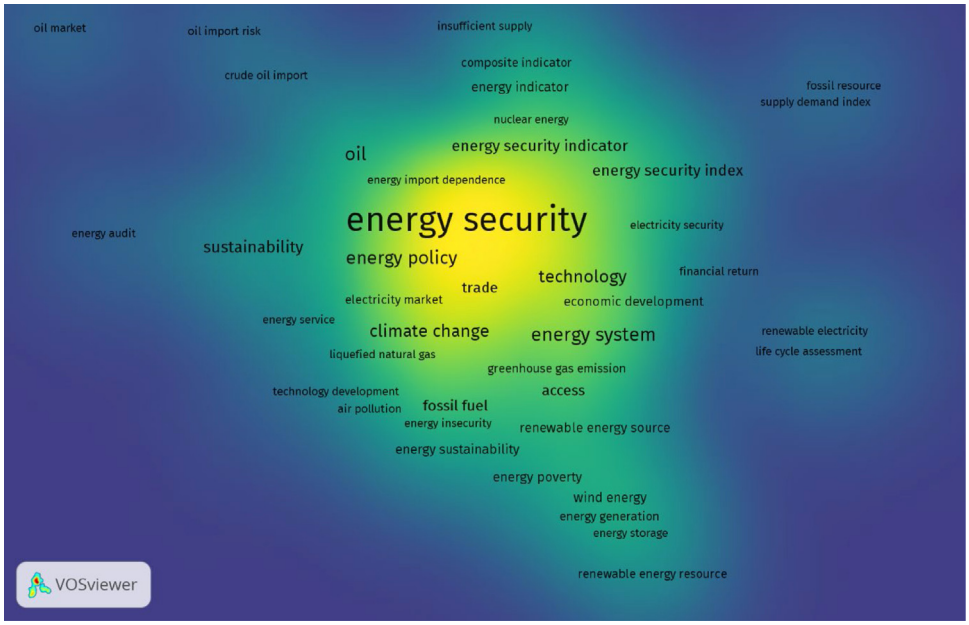

Fig. 10. Hot map (density map) obtained from VOSviewer software.

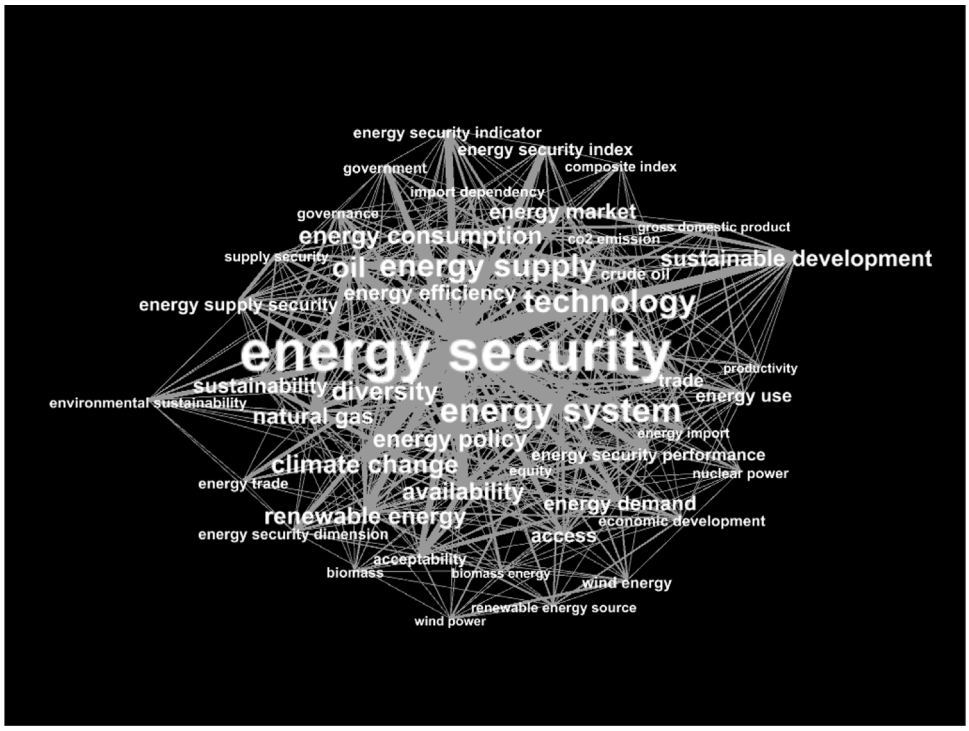

Fig. 11. Coherent vocabulary map in the field of energy security.

to its broad scope. Therefore, in this article, we have studied research trends in the energy security field using the knowledge mapping tool. The present research has been conducted using a meta-synthesis approach, a scientometric approach, and network analysis. A seven-step, multi-compound approach has been used to monitor and select articles in the present study. Following the text mining for one phase, deletion of redundant words, plotting the graph and then grading it with the betweenness centrality & degree of centrality criteria and ultimately deletion of non-semantic words, a knowledge map in the energy security field was presented.

Based on the research results, research conducted on energy security globally (within the remit of this research) has seemingly been compiled by researchers from energy-consuming countries. These countries have always been concerned about energy supply, and their economies usually depend on energy resources for the development and security of energy supply as part of a strategic issue. On the other hand, little research in the energy security field is conducted by countries that produce fossil-fuel energy, with the apparent reason being cheap access to fossil fuels. As shown in Fig. 2, out of all research on energy security, fifty-seven percent of research has been on energy security and its derivatives, 20% on energy supply security, while only 3%

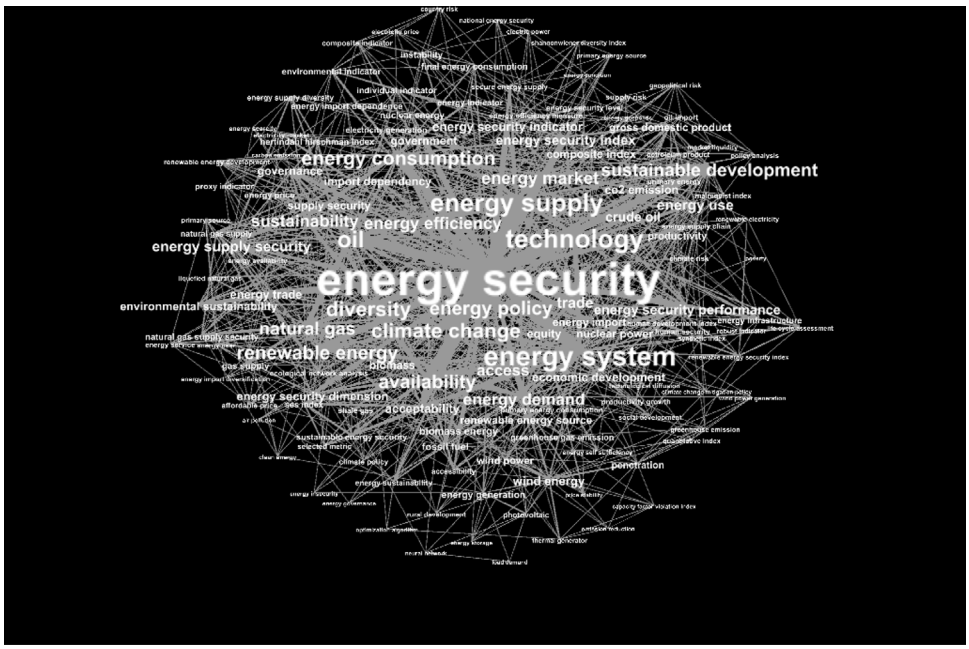

Fig. 12. Coherent vocabulary map according to energy security centrality index using Gephi software.

have focused on energy demand security. Fig. 8, which ranks the leading countries in energy security research, also emphasizes that energy-consuming countries such as China, the United States, Australia, Japan, and Germany are among the top countries where energy security research has been carried out.

Researchers who work on energy security first looked at the concept of energy security from a geopolitical perspective (see Table 1, an article entitled "Ensuring energy security"). Then researchers worked on concepts of energy security and its broader dimensions, including economic, technological, and environmental studies (Table 1, see "Conceptualizing energy security"). Finally, many scientists and theorists have attempted to generate measures to quantify energy security to analyze their energy security situation better while examining energy policy implications (see "Indicators for energy security" in Table 1).

By generating a knowledge map, researchers can identify the sources and direction of knowledge flow and the limitations and shortcomings of knowledge in a field of study. First, by examining the research trends in the energy security field (Fig. 2), oil and gas security and renewable energy have been considered to a reasonable extent. Second, by considering Fig. 10 and the hot map of energy security, the field of renewables has been infused with attention to biomass and wind energy and research on energy security, and although minor, nuclear security.

Furthermore, by looking at the co-occurrence map of keywords in the field of energy security in Fig. 11, the prominent oil and gas position in energy security research is evident, inconsistent with current advertising trends that the oil era is coming to an end. Therefore, by examining the coherent vocabulary map in the field of energy security, it can be said that the most significant dimensions of energy security include "technology", "trade", "acceptability", "productivity", "diversity", "equity", "availability", "governance" and "efficiency" (Fig. 11).

7. Suggestions for future research

In highlighting the replacement of oil and gas with renewables as energy sources in the coming years, it is suggested that renewable energy security can benefit from enhancements in future studies. On the other hand, considering the depletion of energy resources of countries with the oil reserves, the security of energy supply, along with the security of energy demand.

Given that energy security is an interdisciplinary, multidimensional and evolving concept, it is useful to provide studies on the knowledge map of keywords in relation to the concept of energy security (see Fig. 2), including "renewable energy security", "energy supply security" and "energy demand security", etc. which can contribute to generate a more accurate and detailed knowledge map of the concept of energy security. It is also suggested that a better understanding of the environmental dimensions of energy security can be achieved through constructing a knowledge map of sustainable development.

Finally, given that the understanding of energy security problems and the methods used for analyzing energy security problems will continue to play an important role in a deeper and broader understanding of the dimensions of energy security, it is suggested that future research be aimed at generating a knowledge map of energy security problems.

CRediT authorship contribution statement

Alireza Nasr Esfahani: Concept and design, Analysis and interpretation of data, Drafting of the manuscript, Revision of the manuscript, Statistical analysis. **Naser Bagheri Moghaddam:** Concept and design, Analysis and interpretation of data, Revision of the manuscript. **Abbas Maleki:** Analysis and interpretation of data, Revision of the manuscript. **Amir Nazemi:** Analysis and interpretation of data.

Declaration of competing interest

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

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